To direct the reader to the secret original source materials, we have added nuclear test report refs.

DOMESTIC NUCLEAR SHELTERS

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TECHNICAL GUIDANCE

A.W.R.E. Report T17/54	Secret	Operation Hurricane Group Reports : Anderson Shelters.
A.W.R.E. Report E4/55	Confidential	Model Studies of the Reinforced Concrete Structures used in the Montebello Atomic Bomb Trials.

BRITAIN BEGAN SHELTER RESEARCH WHEN EXPOSING ANDERSON SHELTERS & CONCRETE BLOCKHOUSES TO THE 1952 "HURRICANE" NUCLEAR EXPLOSION, BUT IT WAS "SECRET" FOR 30 YEARS...

A HOME OFFICE GUIDE

Originator and Reference	Security Classification	Title
U.S. A.E.C. Manual TM 23-200	Confidential/ Discreet	Capabilities of Atomic Weapons. Editions of June, 1955 and November, 1957.
A.F.S.W.P. Report ITR-1459	Official Use only	Operation Plumbbob. Project 31.4. Evaluation of Industrial Doors subjected to Blast Loading.
A.F.S.W.P. Report ITR-1460	Official Use only	Operation Plumbbob. Project 31.5. Test and Evaluation of Anti-Blast Valves for Protective Ventilating Systems.
A.F.S.W.P. Report ITR-1474	Official Use only	Operation Plumbbob. Project 34.3. Test of Buried Structural-plate Pipes subjected to Blast Loading.
A.F.S.W.P. Report ITR-1475	Official Use only	Operation Plumbbob. Project 34.4. Blast Effects on Air cleaning system.
A.F.S.W.P. Report ITR-1507	Official Use only	Operation Plumbbob. Project 33.6. The Internal Environment of Underground Structures subjected to Nuclear Blast. 11 - Effects on Mice located in Heavy Concrete Shelters.
A.F.S.W.P. Report WT-1461	Official use only	Operation Plumbbob. Project 38.1. - II - Blast Effects on Glass Vacuum Containers.
E.R.D.L. Fort Belvoir Virginia Report 1468-TR 2nd November, 1956.	Secret/ Restricted Data	Field Fortifications Test Exercises. Desert Rock VI. N. J. Davis Jr.
1957 Tripartite Conf. A.W.R.E. Report E4/57	Confidential	The Effects of Shielding a Building from Atomic Blast by another of the same Size and Shape.
A.F.S.W.P. ITR-1447.	Official Use only	Operation Plumbbob. Project 33.5. The Internal Environment of Underground Structures subjected to Nuclear Blast. I - The appearance of Dust.
A.F.S.W.P. Report ITR-1448	Official Use only	Operation Plumbbob. Project 30.1. Field Test of Reinforced Concrete Dome Shelters and Prototype Door.
A.F.S.W.P. Report ITR-1449	Official Use only	Operation Plumbbob. Project 30.2. Response of Dual-purpose Reinforced Concrete Mass Shelter.
C.E.T.G. Preliminary Report ITR-1408, (M.O.D. Ref. No. 378)	Confidential	Operation Plumbbob, Project 1.8B, Effects of Rough Terrain on Drag Sensitive Targets.
A.F.S.W.P. 1957 Tripartite Conf. Paper No. 9	Atomic	Blast Loading of Structures and Target Response. Anderson.
Federal Civil Defence Administration Report WT-801 (deleted). (M.O.D. Ref. No. 72)	Confidential/ Atomic	Operation Upshot/Knothole, Project 21.1. Effects of an Atomic Explosion on Underground and Basement Types of Home Shelters.
Armour Research Foundation Report M024, M.O.D. Ref. Nos. 107, 117 and 118.	Unclassified	Study of the Vulnerability of an Oil Refinery to Air Blast. Summary Report and Vols. 1 and 2.
Armour Research Foundation (M.O.D. Ref. No. 147)	Confidential/ Atomic	Operation Greenhouse, Scientific Director's Report, Interim Report Annexe 3.3, Air Force Sturctures Test Vol.2 - Construction Plans, and Appendix E, Vol.1 - General Blast Loading and Response.
A.F.S.W.P. Report ITR-1129 (M.O.D. Ref. No. 247) May, 1955.	Secret/Atomic	Operation Teapot, Project 3.7, Preliminary Report. Effects of Positive Phased Length of Blast on Drag Type Industrial Buildings (Description of Test Buildings and Predicted and Measured Pressures and Loadings).
University of Illinois Report AFSWP-494. 21st August, 1953. (M.O.D. Ref. No. 311)	Unclassified	Effect of Long Positive Phased Blast Waves on Drag and Defrection Type Targets. N.M. Newmark.
Tri. Con Weapons Effects 1957 Paper AWEC/P(57)55	Secret/Atomic	The Vulnerability of Airfield Runways to Nuclear Explosions. J. E. Henderson.
Home Office Report CD/SA48	Confidential	The Safety-Cost Relationship for Certain Types of Surface and Trench Shelters.
C.E.T.G. Report ITR.1128 Operation Teapot, Proj. 3.6, 1955 (M.O.D. Ref. No. 307A)	Confidential/ Atomic	Evaluation of Earth Cover as Protection to Above-Ground Structures.

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Second Edition 1982

Prepared by the Home Office and the Central Office of Information 1981
Printed in England for Her Majesty's Stationery Office by Hobbs the Printers of Southampton

ISBN 0 11 340777 7 (2462) Dd717557 C40 1/82 G381

HMSO £5.95 NET

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NOTE: THIS BOOK DELIBERATELY OMITS ALL "SECRET" UK. NUCLEAR TESTS OF SHELTERS, FROM 1950s ATMOSPHERIC TRIALS, WHICH WERE STILL SECRET IN 1982!

Contents

Introduction

This manual of technical guidance on the design of domestic nuclear shelters has been prepared by a working group set up by the Emergency Services Division of the Home Office. The working group was asked to consider designs of nuclear shelters which could be made available to members of the public in the United Kingdom who might wish to purchase and install shelters for the use of themselves and their families.

The working group realised that the range of designs which it might produce would not be exhaustive. However, it was aware of the need to give technical guidance to professional engineers to assist them in producing reliable shelter designs. Thus the first three chapters of this book are written to give such guidance.

The other four chapters of the book give detailed designs of five shelters. These five cover a range of types which are applicable to different sorts of houses; they also cover a wide price range. These designs are not intended to be exhaustive, and as explained in the text, the working group is already giving attention to other designs, particularly those which might be incorporated into existing or new houses and also underground shelters of shapes other than box-like and using materials other than concrete. It is planned to publish details of this work at a later date.

The members of the working group are:

Mr J C Cotterill, *Chairman*	Scientific Advisory Branch, Home Office
Dr J R Stealey	Scientific Advisory Branch, Home Office
Mr A Lindfield	Scientific Advisory Branch, Home Office
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Any enquiries concerning this manual should be addressed to the Home Office, F6 Division, and not to individual members of the working group.

Originator and Reference	Security Classification	Title
A.W.R.E. T70/54	Confidential	Measurement of Total Integrated Heat Output.

Chapter 1

Requirements for the design and installation of nuclear shelters

This chapter sets out the effects of nuclear explosions that are relevant to the design of nuclear shelters. Material has been taken from *Nuclear Weapons* (Home Office and Scottish Home and Health Department), published by HMSO, and *The Effects of Nuclear Weapons* (United States Department of Energy and Department of Defence). Reference has also been made to *Introduction to Structural Dynamics* by J M Biggs (McGraw-Hill Book Co). These nuclear weapons effects have been used as a basis for the structural design of nuclear shelters in Chapter 3.

Later sections of this chapter deal with other essential requirements for nuclear shelters, such as ventilation, shelter supplies, food, and shelter strategy. A brief note is added on the question of planning permission, Building Regulations and rating. On some of these subjects reference has been made to the Home Office booklet *Protect and Survive* (HMSO).

1.1 Effects of nuclear explosions

1.1.1 General features of nuclear weapons

The bombs exploded over Nagasaki and Hiroshima were fission or atomic bombs with a power of approximately 20 *kilotons,* equivalent to about 20,000 tons of TNT. In any future nuclear war the kind of weapons which might be used against this country would probably be of the power of half a *megaton* up to several megatons, equivalent to about half a million to several million tons of TNT.

In recent years there has been some discussion of the 'neutron bomb'. This is more correctly called the 'enhanced radiation weapon'. The design of these weapons is such that the range of neutrons from the nuclear reaction is greater than the range of the blast effects. But to achieve this the weapons must be of less than 10 kilotons in power. They are specifically designed for battlefield use and as such would be very unlikely to be used against this country in a strategic nuclear war.

=> (DEBUNKS (NOT!)

Weapons might be exploded on or near the ground, or in the air. Those exploded on or near the ground will produce radioactive dust and dirt which will be carried by the wind and fall to the ground as 'fallout'. Weapons burst in the air will produce insignificant fallout and this will be in the form of very fine particles which will not fall to earth for weeks, months or years later. The bombs dropped on Japan were air bursts and did not produce significant fallout. Weapons would be burst in the air to maximise the range of blast effect at the expense of the later hazards of residual radiation. It is thought that in a nuclear war the UK might expect about 200 megatons of nuclear weapons of various sizes to be delivered against about 80 targets. There would be many areas unaffected by blast; but many such areas might be affected by fallout. There can be no certainty where the weapons might fall. For this reason both blast and fallout radiation must be considered in shelter design, although in many areas a 'fallout shelter' could save many lives.

1.1.2 Energy distribution in nuclear explosions

The enormous energy of a nuclear detonation at ground level is distributed approximately:

- 45% in blast and shock waves
- 35% as light and heat
- 5% as initial nuclear radiation
- 15% as residual radiation in the fallout.

Blast, light and heat are common to both conventional and nuclear explosions; only nuclear detonations produce ionising radiation. Initial nuclear radiation (INR) is emitted within one minute of the explosion, mostly within ten seconds. Residual radiation in fallout comes from the radioactive fission products which are vapourised by the heat of the explosion and condense on the debris and dust sucked up from the ground.

Fire Research Station S.R. Note No. 28/1956	Confidential	Heat Radiation Shields for Defence Against Atomic Explosions. Simms et al.
Fire Research Station F.R. Note No. 280/1956	Unclassified	The Effect of Moisture Content on the Spontaneous Ignition of Wood by Radiation. Thomas et al.

Light and heat energy 1.1.3

This energy consists of visible light, ultraviolet and infra-red rays. The ultraviolet rays are quickly absorbed by the air but the light and infra-red (heat) rays travel great distances and are emitted for several seconds—up to about 20 seconds for a 20 megaton explosion. The intensity of the direct heat radiation received at particular places will depend on such factors as dust, fog, or atmospheric pollution, all of which could absorb much of the radiation. Under *clear* conditions the ranges in Fig. 1 might apply. Distances are in kilometres (miles).

Fig. 1 ***Ranges of heat effects***

	Ground burst		Air burst	
	Main fire zone	**Second degree burns**	**Main fire zone**	**Second degree burns**
1MT	$2\frac{1}{2}$–8 ($1\frac{1}{2}$–5)	10 (6)	3–13 ($1\frac{3}{4}$–8)	15 (9)
10MT	6–19 ($3\frac{1}{2}$–12)	26 (16)	7–32 (4–20)	39 (24)

In the main fire zone, houses not totally destroyed by blast could catch fire. Second degree burns would be sustained by exposed skin. These would be the maximum ranges at which the effects would occur. On most days in the UK the ranges would be much less because of climatic conditions.

To obtain some protection from the heat it is necessary to move out of the direct path of the rays from the fireball; any kind of shade will be of some value. In shelter design, any materials affording protection against ionising radiation or blast will give more than adequate protection against the heat. However it is important to ensure that no exposed parts of the shelter (such as the facings of doors) are made of flammable materials. In the case of shelters made from plastic materials such as GRP (glass reinforced plastic) it is essential that no surfaces should be exposed to the heat pulse. It is unlikely that such plastic materials would catch fire, but they may melt or distort. Since the blast wave follows the heat pulse, such distorted areas may result in lowered blast resistance.

It is considered unlikely that the heat flash from a nuclear explosion would give rise to fire-storms. In the last war, fire-storms were caused in the old city of Hamburg as a result of heavy incendiary attacks and at Hiroshima but not at Nagasaki. A close study of these cities and of German cities where fire-storms did and did not occur revealed several interesting features. A fire-storm occurred only in an area of several square miles, heavily built up with buildings containing plenty of combustible material and where at least every other building in the area had been set alight. It is not considered that the initial density of fires, equivalent to one in every other building, would be caused by a nuclear explosion over a British city. Studies have shown that due to shielding, a much smaller proportion of buildings than this would be exposed to the heat flash. Moreover, the buildings in the centres of most British cities are now more fire-resistant and more widely spaced than they were 30 to 40 years ago. This low risk of fire-storms would be reduced still further by the control of small initial and secondary fires.

⇒ DEBUNKS SOOT "NUCLEAR WINTER"!

There are two main hazards from a large area of fire to the occupants of shelters. One is the transmission of heat through the earth and shelter wall. In most cases this would make for discomfort rather than danger, particularly in underground shelters. The major danger is the possibility that the gaseous products of combustion, mainly carbon dioxide and perhaps carbon monoxide, might be drawn into the shelter. These dangers may be mitigated by taking advantage of the fact that the arrival of fallout is unlikely to occur for about half an hour after the explosion and a fallout warning will be given (for details see the booklet *Protect and Survive*). The intervening time might be used to try to extinguish or damp down any nearby fires. This may not be possible in many cases where a fallout warning has already been given based on ground bursts further upwind than the local bomb.

Crater formation and ground shock 1.1.4

When a nuclear weapon bursts near the ground much of the energy is expended in making a crater. At the same time a shock wave is transmitted outwards through the ground.

Crater formation

A large amount of vapourised or pulverised material is sucked up by the ascending fireball. Larger amounts are gouged out and deposited on the perimeter of the crater making an elevated lip roughly equal in width to the radius of the crater itself. The size of the crater, for a weapon of given power, will depend on the nature of the ground and

RFN.567, January, 1950 (M.O.D. Ref. No. 304)	Secret	Investigation of Fire Damage Caused by the Atomic Bombs on Hiroshima and Nagasaki, by J. B. Hawker, and O.C. Young of the British Mission to Japan.
A.F.S.W.P. Report WT.774 (MOD Ref.No. 77)	Confidential/ Atomic	Operation Upshot-Knothole, Project 8.11A. Incendiary Effects on Building and Interior Kindling Fuels, 1953. Report by U.S. Department of Agriculture Forest Service, Forest Products Labatory.

crater dimensions for weapons of various powers in different soils are given in Table 8 of *Nuclear Weapons*. Those figures are not repeated here since in themselves they have no relevance to shelter construction. What is of importance for shelter construction is the ground shock which is propagated outwards from the crater.

Ground shock

The ground shock effects of a megaton surface burst are similar to those of an earthquake of moderate intensity, but the pressure in the ground shock wave decreases more rapidly with distance. The ground shock effects on buildings above ground are irrelevant since they do not occur beyond the distances at which those structures are in any case destroyed by air blast. The effect of the ground shock on structures below ground depends on the ability of those structures to adjust to the ground movement. Damage will depend on:

Duration of blast wave (hence power of weapon).	Moisture content of soil.
Type of soil.	Depth of the structure below ground.
	The shape of the structure.

Small, self-contained structures will generally move bodily with the earth movement; a spherical or similarly shaped structure is better than one irregularly shaped; flexible structures usually adjust to some ground movement, particularly long flexible structures such as pipes. A rigid rectangular structure, such as a concrete box, would be vulnerable to earth movement at its edges and particular attention must be paid to the reinforcing links at these locations. The information in Fig. 2 is taken from *Effects of Nuclear Weapons* and refers to structures in wet clay. Distances would be halved in dry rock. 'Moderately deep' is defined as structures where the ratio of depth of cover at the crown to the span is greater than unity. More deeply buried structures would suffer less damage.

Fig. 2 ***Damage criteria for moderately deep underground structures***

Type	Damage type	Metres (feet) from 1 MT GB	Nature of damage
Relatively small, heavy well-designed structures	Severe	450 (1,500)	Collapse
	Light	850 (2,800)	Slight cracking; severance of brittle external connections
Relatively long flexible structures; e.g. buried pipes and tanks	Severe	500 (1,700)	Deformation and rupture
	Moderate	670 (2,200)	Slight deformation and rupture
	Light	850 to 1,000 (2,800 to 3,300)	Failure of connections

Thin-walled, self contained structures buried in wet clay should be undamaged by ground shock if sited at a distance greater than 1,000 metres (3,300 feet) from the ground zero of a ground burst megaton weapon. In dry ground the structures would be undamaged by ground shock at a smaller distance from ground zero.

This is not the whole story however. At locations where structures would suffer only light damage from ground shock the overpressure in the blast wave from one megaton explosions would be of the order of 2,800 kiloPascals (400 psi), and this would be the major factor causing damage. This subject is dealt with in the next section. None of the shelter designs given later take ground shock into account. Most do however give some protection against air blast.

1.1.5 Air blast

Characteristics of the blast wave

When an explosion occurs, a blast wave is propagated away from the point of burst. The distribution of overpressure (i.e. the excess above atmospheric pressure) along a radial line from the centre of burst is indicated in Fig. 4. The blast wave travels with a characteristic velocity and peak overpressure. This decays behind the front as shown in Fig. 4. At the same time the air behind the front is moving outward at a high velocity and this wind produces 'drag' forces on any object encountered. At a fixed point on the ground the variation of overpressure and dynamic pressure with time is shown in Fig. 5.

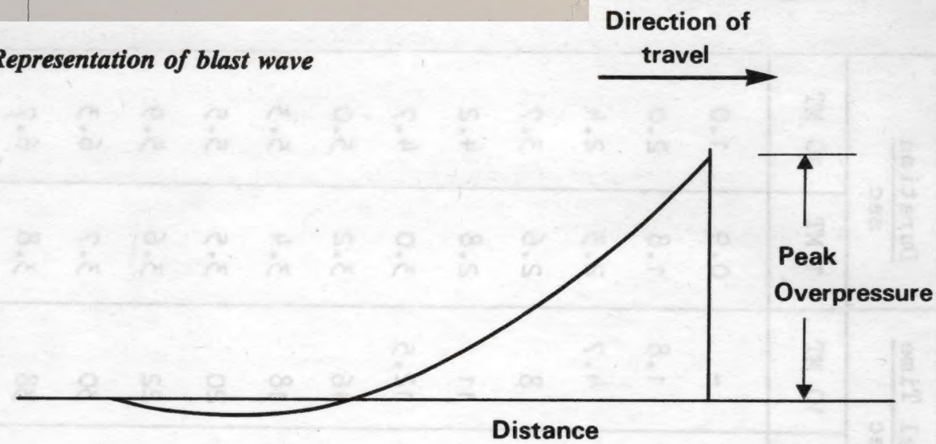
Fig. 3 gives some quantitative information on the relationship between the various parameters of the blast wave. In this table, the last column refers to the duration of the positive phase of the blast wave, i.e. the time between blast arrival and the first return to ambient pressure.

Fig. 3 ***Characteristics of blast waves from 1 MT and 10 MT nuclear burst optimum height air blast***

Distance from GZ	Peak Overpressure kPa (psi)		Windspeed Metres/sec (mph)		Arrival Time sec		Duration sec	
Km (miles)	1 MT	10 MT	1 MT	10 MT	1 MT	10 MT	1 MT	10 MT
1 (0.6)	980 (140)	4200 (600)	980 (2200)	-	0.9	-	0.9	1.0
2 (1.25)	200 (29)	1050 (150)	400 (900)	980 (2200)	4.0	1.8	1.8	2.0
3 (1.9)	130 (18)	380 (54)	180 (400)	805 (1800)	6.0	4.7	2.3	2.4
4 (2.5)	63 (12)	220 (31)	128 (285)	490 (1100)	9.0	8	2.6	3.7
5 (3.1)	56 (8)	170 (24)	106 (238)	277 (620)	12	11	2.8	4.2
6 (3.8)	42 (6)	135 (19)	81 (182)	200 (450)	14	12.5	3.0	4.7
7 (4.4)	33 (4.7)	110 (16)	69 (155)	170 (380)	18	16	3.2	5.0
8 (5.0)	27 (3.8)	90 (13)	56 (125)	143 (320)	22	18	3.4	5.3
9 (5.6)	24 (3.4)	77 (11)	48 (108)	125 (280)	26	20	3.5	5.5
10 (6.2)	21 (3.0)	63 (9)	40 (90)	114 (255)	28	22	3.6	5.9
12 (7.5)	15 (2.2)	46 (6.5)	31 (70)	96 (215)	31	30	3.7	6.3
15 (9.4)	10 (1.5)	34 (4.8)	24 (53)	72 (160)	45	38	3.8	6.7
20 (12.5)	7 (1.0)	22 (3.3)	17 (37)	46 (103)	59	53	4.0	7.5
25 (16)	5 (0.75)	15 (2.2)	9 (20)	32 (72)	70	67	4.2	7.8

A.W.R.E. Report T86/54.	Secret	Measurement of Air Blast.
A.W.R.E. Report T9/58	Confidential	Measurement of Blast Pressures Associated with Various Service and Civil Defence Targets.
A.W.R.E. Report T1/58	Confidential	Operation Buffalo. Air Shock Measurements on Rounds 1 and 2.
A.W.R.E. Report T42/58 Dec. 1958.	Confidential	Operation Antler. Measurement of Ground Shock.

Fig. 4 ***Representation of blast wave***



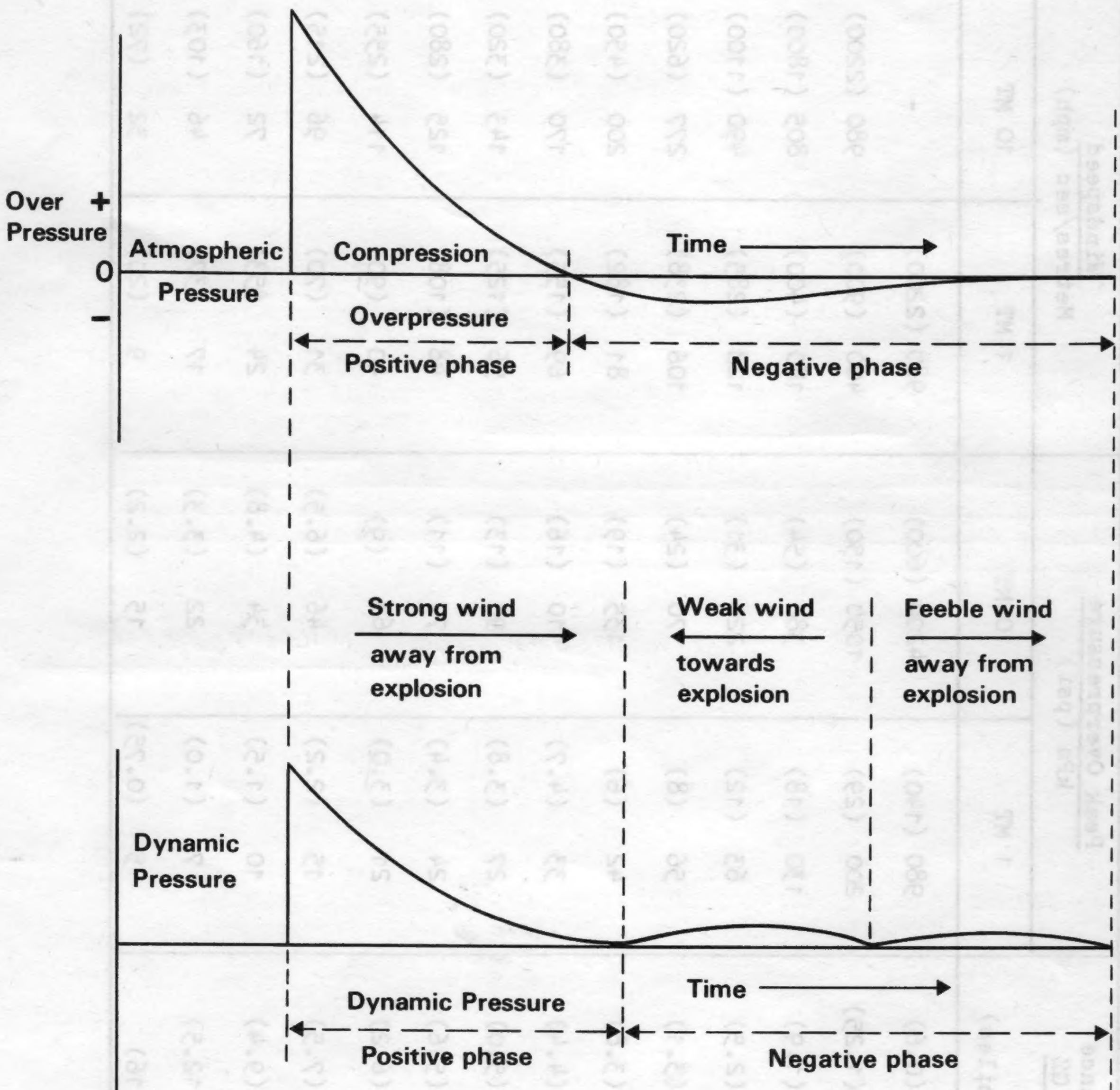


Fig. 5 ***Variation of overpressure and dynamic pressure with time at a fixed location***

A.W.R.E. Report E1/57	Confidential	Incident Stress on Buried Shelters from Megaton Bombs.

Damage caused by blast wave

When the blast wave strikes an object such as a building there is a diffraction effect producing forces which result from the higher pressures due to reflection of the wave on the front face of the object and also from the time lag before the overpressure acts on the rear face. The overpressure on the face towards the explosion is momentarily increased by a factor of 2 to 8. As the wave moves around the building this reflected pressure on the facing wall falls rapidly and the overpressure is exerted on the roof and side walls of the building. As the blast wave moves past the building, it reforms on the rear of the building with a slightly reduced intensity.

Immediately behind the wave front the air is moving away from the explosion at a high velocity and this dynamic pressure or 'wind' produces drag forces on any objects encountered. Thus the total loading on structures consists of three parts: a) the initial diffraction effect; b) the effects of the general overpressure; and c) the drag loading.

The dynamic pressure is obtained from the following expression:

$P_d = \frac{1}{2}\varrho v^2$, where ϱ is the air density and v is the velocity of the air particles

The drag pressure on an object in the path of the wind is the dynamic pressure times the appropriate drag coefficient, C_d. The negative overpressure phase, or suction, indicated in Fig. 5 is relatively unimportant and can be ignored for structural design purposes.

Before the blast wave has surrounded the building there will be a tendency for the building to move in the direction of the blast wave. If the building has, say, less than 5 per cent of its entire surface as doors and windows, it will be subject to this maximum pressure whilst the shock front passes from one end of the building to the other (taking about 1/10th of a second to traverse a building of 23 metres (75 ft). With few apertures there may be insufficient time for the inside pressure to build up to the value outside and the building will bear the crushing weight of the overpressure. In buildings with more doors and windows, equalisation of pressure occurs fairly quickly and the pressure inside may remain high after the blast wave has passed, resulting in the building exploding. Buildings may have a relatively high resistance to external forces but comparatively low resistance to internal pressures.

These factors have a relevance to shelters which are unsealed, i.e. without doors. The duration of the overpressure phase from a 10 KT weapon at the point at which it has a peak of 105 kPa (15 psi) is 0.4 second. With a small unsealed shelter the blast wave will pass rapidly and the pressure inside may build up to only about 35 kPa (5 psi), which the occupants could survive. However the duration of the positive phase of the blast wave from a 1 MT weapon at the point at which it has a peak overpressure of 105 kPa (15 psi) is about 2.5 seconds; during this time the pressure inside an unsealed shelter could build up to the outside pressure. This could result in casualties amongst the occupants. Additional injury, possibly fatal, may well be caused by the sudden translational movement of the occupants during the inrush of the blast forces. For these reasons, shelters which have been designed for battlefield use against kiloton weapons are not necessarily suitable for use, say, in the UK where the expected attack would be by weapons in the megaton range.

Transmission of air blast through the ground

In the section above, the total loading on structures from a blast wave was said to consist of three parts. Of these three, only the general effect of overpressure is relevant to structures below ground. The drag effects will be of some importance for any parts of the below-ground structure protruding from the ground (such as air vents, etc.).

As the pressure wave moves outward from the point of detonation it exerts a downward pressure on the ground. The attenuation of this 'airslap', as it is called, depends on the nature of the soil. For shallow buried structures (a few inches below ground) the magnitude of the air blast overpressure may be taken as the effective load on the structure. For deeply buried structures (with the cover equal to or greater than one-half the minor span) most of the problems peculiar to the design are in the realm of soil mechanics and wave propagation.

For shallow buried structures, then, the primary effect of burial is to eliminate the reflection and drag components of the loading. The design of the roof is not very different from the design of the roof for an above-ground structure. The vertical walls of a rectangular structure are subjected to smaller loads than in the case of above-ground structures. In dry, well-compacted soils the lateral blast pressures on the vertical faces of the walls of shallow buried structures has been found to be as low as 15 per cent of the blast pressure on the roof. However in porous, saturated soil this lateral blast pressure is likely to approach 100 per cent of that on the roof. The pressure on the bottom slab which is integral with the walls may be from 75 to 100 per cent of that on the roof.

For deeply buried structures (where the earth cover is equal to or greater than half the width) there are three major effects in addition to those given above for shallow buried structures. The first two of these have an advantageous effect. These effects are: i) the overpressure is attenuated with depth; ii) the soil acting as an arch above the structure takes an appreciable part of the load; and iii) the duration of the positive phase is increased. Of minor importance is the fact that the extra weight of overburden represents a force on the roof slab.

The arching effect of the soil can be very important. If the deformability of the buried structure is the same as that of the surrounding displaced soil, the loads on the structure will be determined by the free field pressures induced in the soil by the blast wave. If the structure is more deformable than the surrounding soil, the pressure on the buried structure will be considerably lower than the free field pressure at a given depth. In this case the structure deflects away from the soil and part of the blast-induced pressure is deflected around the structure rather than through it. Structures such as arches and domes develop significant arching resistance in soil; rectangular structures do so to a lesser extent.

Detailed design guidance for buried structures is given in Chapter 3 of this book. But, as a rule-of-thumb, the depth of earth required for a buried structure can be determined by that which is required to give protection against nuclear radiation which might be expected at the design overpressure of the structure (see Figs. 7 and 8).

One further point should be mentioned. A compromise between above-ground structures and buried structures may sometimes be desirable. This is particularly so in the United Kingdom where the water table is frequently quite high. Semi-sunk structures have the advantage of avoiding the worst of the water problems and also of utilising the earth excavated to cover the part of the structure above ground. If this is done, it is desirable to attenuate the diffraction effects and the drag loading effects referred to earlier. This can be done by improving the aerodynamic shape of the mound. Ideally the earth slope should be 14° or less to the horizontal.

Casualties caused by air blast

Injuries or death from air blast can be caused in four ways:

- By direct effect of pressure on the body; lung rupture would be the determining injury.
- Indirectly, by the body being thrown against hard objects.
- Indirectly, by the body being hit by pieces of flying debris.
- Indirectly, by the collapse of buildings on to the occupants.

The relationship of the first three of the mechanisms can be seen from the following example. A person exposed to the blast effect from a 1 MT groundburst at a distance of 1.6 km (1 mile) from ground zero (280 kPa or 40 psi) would be killed by direct effects; if he were standing in the open within 4.5 km (2¾ miles) of ground zero (about 35 kPa or 5 psi) he would be carried along by the wind and might collide with an obstacle; out to about 7.5 km (4¾ miles) (about 14 kPa or 2 psi) he could be struck by missiles carried by the wind. Because of the danger from wind-borne debris it is important that potentially fragile fixtures such as ventilator pipes should be well protected.

Death and injuries caused indirectly by damage or destruction of houses is classified as in Fig. 6. The last column refers to the probability of death or injury to people in the houses at the time of burst.

Fig. 6 ***Approximate ranges of blast damage to UK houses (from 1 MT groundburst)***

Designation	Radial distance	Overpressure	Effect	Death/injury
A ring	Up to 2.5 km ($1\frac{1}{2}$ mi)	77 kPa plus. (11 psi)	Houses totally destroyed	High probability of death or serious injury
B ring	2.5 to 3.5 km ($1\frac{1}{2}$ to $2\frac{1}{4}$ mi)	77 to 42 kPa (11 to 6 psi)	Houses irreparably damaged	About 10% killed; 35% trapped; others injured
C ring	3.5 to 9 km ($2\frac{1}{4}$ to $5\frac{1}{2}$ mi)	42 to 10 kPa (6 to 1.5 psi)	Houses with moderate to severe damage	About 25% trapped or seriously injured at inner edge of ring
D ring	9 to 14 km (6 to 9 mi)	10 to 5 kPa (1.5 to 0.75 psi)	Houses lightly damaged	No deaths; few injuries expected

The distances would be increased by about 30% for air bursts.

The debris problem

From Fig. 6 it can be deduced that the problems of debris around buried shelters might be serious in some locations near to ground zero. It is important that entrances or escape hatches and ventilation pipes where included should be as far as possible from nearby buildings — at least a distance equal to one-half the height (measured to the eaves) of the nearest building.

Trees are very vulnerable to long duration blast waves and in some areas these might cause obstruction to shelter entrances. The blast from a 1 MT groundburst would blow down 90 per cent of trees at a distance of 6 km ($3\frac{3}{4}$ miles), 30 per cent at 7 km ($4\frac{1}{2}$ miles) and cause damage to branches out to 10 km ($6\frac{1}{4}$ miles).

Initial nuclear radiation (INR) 1.1.6

Neutrons and gamma rays are emitted instantaneously by a nuclear explosion and these are followed by the gamma radiation from the intensely radioactive products in the fireball. This radiation is called initial nuclear radiation and is defined as that radiation emitted within one minute after detonation. In fact most of this hits the ground within a few seconds since the rapid rise of the fireball quickly takes the gamma rays and neutrons out of range. The phenomenon of initial nuclear radiation is very complex and not completely understood, but four facts are of importance for shelter design.

1. Range of INR

The intensity of INR falls off very rapidly with distance. The dose of INR received by a person in the open 2.5 km ($1\frac{1}{2}$ miles) from a 1 MT burst would give only a 50 per cent chance of survival. At 2.8 km ($1\frac{3}{4}$ miles) the dose received would be negligible. At those distances, of course, anyone in the open would be killed by the blast. One important difference between kiloton and megaton weapons is the relationship between blast and INR ranges. With the smaller kiloton weapons the range of INR extends beyond the range of lethal blast; the reverse is true for megaton weapons. The Hiroshima and Nagasaki weapons were in the kiloton range and produced lethal INR effects. Fig. 7 gives the approximate exposures in roentgens of INR at locations where the blast overpressures are significant. Shelters designed to withstand a given overpressure should also be designed to protect against this level of INR. Overpressures are given in kiloPascals (psi).

Fig. 7 ***Exposures of INR from surface burst (in roentgens)***

Overpressure	315 (45)	105 (15)	77 (11)	42 (6)	10 (1.5)	5 (0.75)
100 KT	300,000	20,000	9000	500	<1	<1
1 MT	70,000	1,000	250	2	<1	<1
10 MT	20,000	15	<1	<1	<1	<1
20 MT	9,000	1	<1	<1	<1	<1

Exposure would be lower from air bursts of the same weapon power. The figures given refer to thermonuclear weapons with 50 per cent fission yield. These figures may vary from 25 per cent to 150 per cent of the values given in the chart.

2. Shielding for INR

INR has greater energy and penetration than the radiation from fallout. The intensity of both INR and fallout radiation are reduced in proportion to the density of the shielding material. This can be expressed in terms of the 'half-value thickness' which is the thickness of a particular shielding material required to halve the radiation dose-rate. The approximate half-value thicknesses of some shielding materials against INR are given in Fig. 8.

Fig. 8 ***Half-value thicknesses of shielding materials***

	Against INR mm	(inches)	Against fallout radiation mm	(inches)
Steel	38	(1.5)	18	(0.7)
Concrete	152	(6.0)	56	(2.2)
Earth	190	(7.5)	84	(3.3)
Water	330	(13.0)	122	(4.8)
Brickwork	157	(6.2)	71	(2.8)

The half-value thicknesses of these materials against fallout radiation are given for comparison. They will be referred to later.

3. Slant incidence of INR

Most of the INR from a nuclear explosion arriving at a given point comes in a direct line from the fireball. There is a certain amount of scattering known as 'skyshine' which means that some initial gamma radiation might be received by a person shielded by a barrier from the light and heat flash (see Fig. 10). The amount of scattering of initial gamma radiation depends upon a number of factors, but probably amounts to about 10 per cent of that in the main beam. This means that though an underground or semi-sunk shelter might be shielded from the major part of the initial gamma radiation a certain amount could be received through the roof or sides of the shelter (if semi-sunk) by what is known as 'angular distribution'. However this benefit of shielding by nearby buildings cannot be taken into account in calculating the protection afforded by a shelter since the location of the source of the initial gamma radiation cannot be known.

4. Rate of emission of INR

The rate of delivery of initial nuclear radiation has some relevance to actions that might be taken immediately after a nuclear burst. Fig. 9 gives the percentage of initial gamma radiation dose received as a function of time for 20 KT and 5 MT air bursts. It can be seen that in the former case about 65 per cent and in the latter case 5 per cent of the total initial gamma radiation dose is received during the first second. In the case of the higher yield weapon it can be seen that if some shelter could be obtained within one second of seeing the explosion flash, such as by falling prone behind some substantial object, it could make the difference between life and death. Such an action would also help to prevent the translational effect of the blast.

1.1.7 Residual radiation from fallout

Nature of fallout

Fallout from a groundburst weapon consists of molten and solidified particles of earth on to which the radioactive products of the detonation have condensed. It has the consistency of fine to coarse sand particles with size varying from 20 to 700 micrometres. Particles smaller than about 20 micrometres would most probably remain in the stratosphere and come down as late fallout weeks, months, or even years later; by this time their radioactivity would have decayed considerably. The fall times from various heights of particles of various sizes are given in Fig. 11.

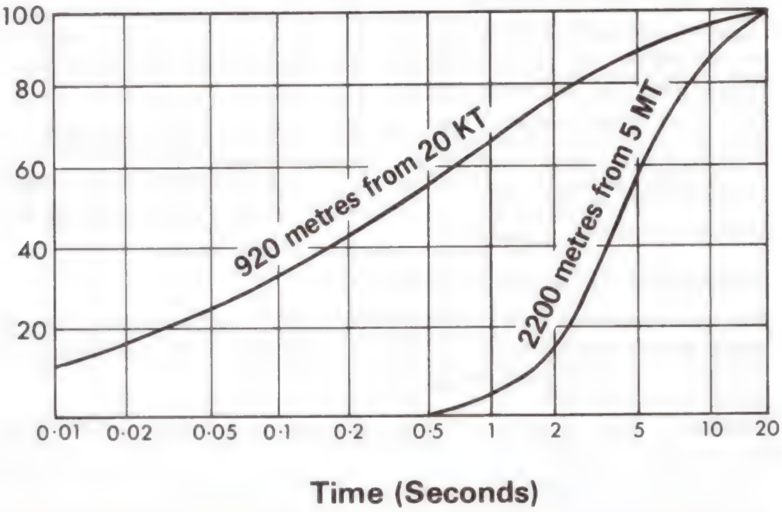
The time taken for fallout to be deposited in any one place varies from about half an hour close to the explosion to many hours further downwind. It is particularly important that people get under some kind of cover during this period to avoid fallout particles getting on the skin. Anyone who is caught out during fallout deposition should certainly cover the head and exposed skin and remove the contaminated clothing before entering shelter. No special protective clothing is required since no kind of clothing will prevent the gamma radiation from fallout reaching the body. If anyone has to emerge from shelter after the fallout has been deposited on the ground it would be useful to wear waterproof boots and gloves with a coat over the indoor clothing. Again these should be removed before re-entering the shelter. Any exposed skin should be washed after any contact with fallout particles.

A.W.R.E. Report No. T37/58	Secret/Atomic U.K. Eyes Only	Operation Antler. The Shielding from Initial Radiation Afforded by Soil.

A.W.R.E. Report T53/57	Secret U.K. Eyes Only	Operation Buffalo. Naval Radiological Measurements. Final Report Part 1. The Polar Distribution of the Flash Gamma Radiation.

Admiralty Research Lab. ARL/R1/R866 July, 1958.	Secret U.K. Eyes Only	Naval Radiological Measurements on Operation Grapple. The Energy of the Flash Gamma Radiation. Allwood.

Fig. 9 ***Percentage of total initial gamma dose received***



A.W.R.E. Report T59/57	S. Atomic U.K. Eyes Only	Operation Buffalo. Neutron Measurements.
A.W.R.E. Report E9/57	Secret/Atomic/ Discreet C.C.	On the Rise of an Atomic Cloud.

A.W.R.E. Report T34/58	Confidential	Gamma Dose-Distance Measurements at Operation Antler.

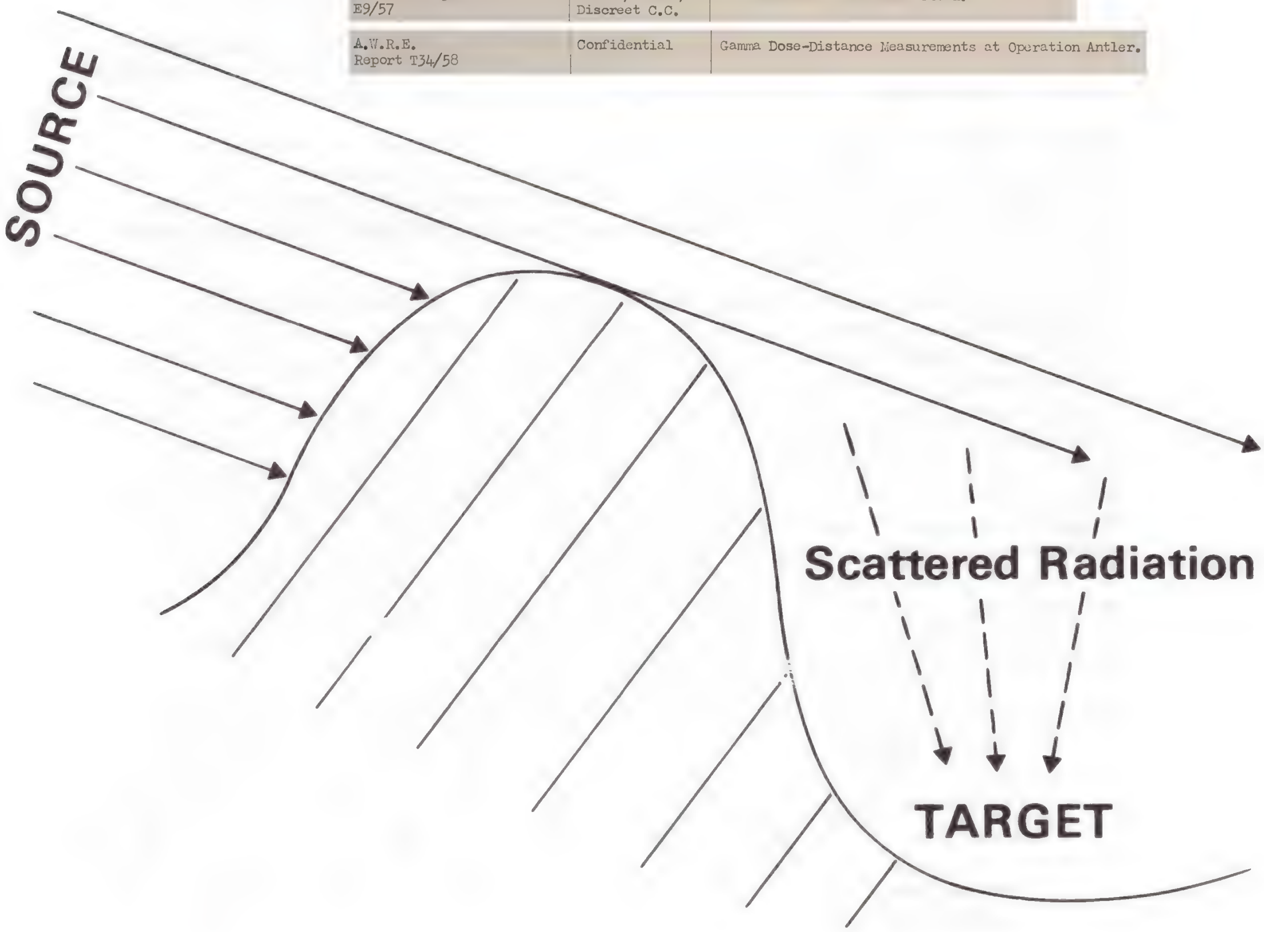


Fig. 10 ***Target exposed to scattered gamma radiation from a nuclear burst***

A.W.R.E. Report H12/52	Official Use Only	The Penetration of Gamma Radiation through the Walls of a Slit Trench.

The nature of fallout particles has an influence on the filtration requirements for shelters. If the air coming into the shelter follows a tortuous path such as is provided by an inverted U shape or a cowl over the air intake, the need for filtration is minimised, if not entirely eliminated. The fallout particles will tend to fall to the earth rather than be carried along by the air current into the air duct. In any case the fallout particles are in the air for a limited period of time in the early hours after the burst so that if filtration is thought desirable, it need only be for that limited time. It would however be better to avoid drawing air into the shelter whilst the fallout is being deposited, if it is possible to know when this is taking place.

If a filter is incorporated into shelter design two points should be considered. The first is that a coarse filter is all that is necessary; a fine filter runs the risk of becoming blocked by ordinary atmospheric dust with resultant reduction of air supply. The second point is that if a filter is likely to become contaminated with radioactive dust then it should be placed outside the shelter.

Protection from fallout radiation

Protection against the radiation from fallout can be achieved in three ways. Consideration must be given to *duration* of exposure, *distance* from the fallout, and *density* of materials between the person and the fallout.

Duration. The damage caused by radiation to the body is cumulative (although the body does show a capability of some recovery). Thus it is important to reduce the time of exposure to radiation. In addition to this the radioactivity from fallout decays in a predictable manner by what is known as the '7/10 law'. Thus a dose rate of 1000 roentgens per hour at one hour after burst will decay to 100 roentgens per hour at seven hours after burst and 10 roentgens per hour at 49 hours (or two days) after burst and so on. This rapid decay means that, except in very severely contaminated areas, it is unlikely that anyone would have to stay continuously in shelter for two or three weeks. Local authorities will tell people when the intensity of the radiation has fallen to levels which make it safe to emerge from shelter for one or more hours. This time, which will gradually increase, can be used to ventilate the shelter better and attend to necessary tasks.

Distance. Protection can be achieved too by keeping as far away from the fallout as possible. A person standing on ground evenly contaminated by fallout would receive half his radiation dose from a circle of about 7.5 metres around him. Thus the floor of an underground shelter or a position in a house as far as possible from the roof and outside walls offers the best protection.

Density. The most important way of reducing the intensity of radiation is by sheltering behind some dense material. As explained, the level of radiation is reduced as it passes through any material but the greater the density of the material, the greater the reduction. The thickness of some materials required to reduce the intensity of fallout radiation to one half were given in Fig. 8. Glass gives little or no protection against radiation and many light materials, such as clothing, bedding etc., afford little protection. However, shelters can be constructed from such materials as glass reinforced plastic (GRP) which does not give much protection itself but can be buried in the ground; the earth cover then will give protection. A layer of 375 mm (15 inches) of earth or 250 mm (10 inches) of concrete over a shelter area would reduce the intensity of the radiation inside the shelter to 1/100th of the intensity outside. This reduction is called a protective factor (PF). A method for calculating protective factors is given in Chapter 2. It is designed for calculating the PFs of buildings. When applied to buried shelters the table dealing with penetration through the roof may be all that is needed.

Fig. 11 ***Time in hours for rough particles of different sizes to fall to the ground from specific heights***

Particle diameter in microns	500	350	200	100	75	50
Falling from metres (feet)						
25,000 (80,000)	1.6	2.3	4.5	12	22	49
18,000 (60,000)	1.3	2.0	3.7	9.5	17	36
12,000 (40,000)	1.0	1.5	2.8	6.8	12	25
9,000 (30,000)	0.8	1.2	2.2	5.3	9	19

Originator and Reference	Security Classification	Title
A.F.S.W.P. Report WT.348 (M.O.D. No.52)	Confidential	Operation Jangle. Gamma-Ray Spectrum Measurements of Residual Radiation.

Further comments on protection against INR and fallout radiation

From Fig. 7 it can be seen that a person on the outer edge the 'A' ring at 77 kPa (11 psi) from a one megaton explosion might receive a dose of about 250 rads INR. This would not in itself be lethal and even some rudimentary shelter would reduce the dose. At this same point the proportion of the population in houses surviving though injured might be about 40 per cent. Nearer to the point of burst the survivors would be fewer but the INR higher. It is in fact in the areas where blast shelters can give the greatest saving of life that INR becomes important, and so must be protected against. As a general rule, shelters designed to protect against 77 kPa (11 psi) and above should also give protection against INR. In most cases however, the required thicknesses of earth, concrete, etc. to give blast protection will also give the required INR protection.

Fig. 12 gives a comparison of the protective factors against INR gamma, neutrons and fallout radiation of some typical buildings. The data has been taken from *Effects of Nuclear Weapons* and the choice has been made of those buildings which are reasonably comparable with structures in the UK. The wide range of values is due partly to uncertainty in the data (since some have been calculated and others derived from weapons trials) and partly to the fact that protection to some extent is determined by the position in the building where the protective factor is measured.

Fig. 12 ***Protective factors of various buildings against initial gamma, neutron and fallout gamma radiation***

Structure	Initial gamma	Neutrons	Fallout gamma
1 metre underground	250–500	100–500	5000
Shelter partly above ground: with 600 mm earth	15–35	12–50	50–200
900 mm earth	50–150	20–100	200–1000

Originator and Reference	Security Classification	Title
U.S.N. Radiological Def. Lab. Report USN/RDL-420 TIL P.62382	O.U.O. Discreet	Application of the Scintillation Spectrometer to Radioactive Fallout Spectra Analysis.
A.W.R.E. Report T-31/58	Confidential	Operation Buffalo. The Attempted Decontamination of Roofs by Wash-down.
A.W.R.E. Report T-35/58	Confidential	Operation Antler. Neutron Induced Activity in Materials Used in Items of Military Equipment. Vol. 1. Text. Vol. 2 Figures.
C.D.E.E. Porton. Tech. Paper (R)22 13th May, 1959	Confidential	Radiological Decontamination. Further Studies on the Removal of Dry Fallout from Clothing. E. Neale and Elizabeth H. Letts.
1957 Tripartite Conf. Paper AWEC/P(57)211	Secret/Atomic	Neutron Induced Activities in Soil.
1957 Tripartite Conf. Paper AWEC/P(57)210	Confidential	An Investigation into Neutron Induced Activities of Food-stuffs and Medical Supplies at Buffalo, Round 1.
A.W.R.E. Report T22/57	Confidential	Operation Buffalo, Decontamination Group Report, Parts 1-4.
A.W.R.E. Report O-49/55	Official Use Only	A Guide to Radiological Decontamination After a Nuclear Explosion or Radiological Attack.
A.W.R.E. Report T4/57	Confidential	Decontamination of Radioactively Contaminated Drinking Water in the Field.
Ministry of Supply DAW(Plans) Note 15.	Confidential	Neutron Induced Radioactivity. Garrard and Bassett.
12th Tri. Conf. on Tox. Warfare Paper TCR8/57	Official Use Only	The Effect of Induced Activity in Soil on Dose-Rate from Fallout. G. C. Dale.
12th Tri. Conf. on Tox. Warfare Paper TCR20/57	Confidential	Decontamination of Personnel and Equipment - Techniques and Equipment. Catherall and Stevenson.
A.W.R.E. Report T28/57	Unclassified	Operation Buffalo. Measurement of the Radioactivity of Water Contaminated by Fallout.
AWRE Report O-22/54	Secret	The Decontamination of Radioactive Clothing Part 1. Laboratory Investigations.
AWRE Report O-23/54	Secret	The Decontamination of Radioactive Clothing Part 2. Laundry Investigations and Recommendations.

1.2 Other design requirements

The next section will discuss the needs for protection against blast and radiation on the basis of the facts already presented. Here we have to consider other important matters that must be taken into account in shelter design. Not all the requirements below will be applicable to every shelter design. But all the matters referred to should be considered when planning, designing or installing any shelter.

1.2.1 Space requirements

This requirement is very closely related to the one following – ventilation. It is, however, worth considering the two separately. For family shelters the ***minimum*** requirements are:

Volume per person	1.8 cubic metres	(65 cubic feet)
Total volume	11.3 cubic metres	(400 cubic feet)
Floor space/person	1.0 square metres	(10 square feet)
Total floor space	6.0 square metres	(65 square feet)
Head room (desirable)	2.0 metres	(6 feet 6 inches)

These requirements are most applicable to purpose-built concrete or thin walled shelters. They are not applicable to *ad hoc* shelters which are unsealed. In the latter case an attempt should be made to provide as much space as possible but they are intended for a short occupancy and they will depend on natural ventilation.

The amount of floor space provided will depend to some extent on the bunking arrangements proposed. If double bunks are installed, this will release more floor space for other purposes.

These requirements apply specifically to the space regarded as the 'living area' of the shelter. There may be additional space available in the stairway or an alcove reserved for a chemical toilet. Such should be additional to the requirements above.

1.2.2 Ventilation and filtration

Applicability

These requirements apply to sealed shelters (i.e. with a permanent door closure). Shelters which depend on natural ventilation should be so planned that air movement through the shelter will be possible. Even so, it may be necessary in some cases to assist this process by *ad hoc* means. In considering air filtration, reference should be made to section 1.1.7 where the nature of fallout particles is discussed.

Basic equipment

(a) Air intake with inlet screen or coarse filter. This should be a minimum of 450 mm (18 inches) above the ground and sited with regard to probable debris after an explosion.

(b) Fixed metal piping to the shelter.

(c) For shelters of Type 4 (see Fig. 13) an inlet blast valve.

(d) Flexible or fixed tubing to the fan.

(e) Fan or air pump. This should be manually operated for preference. An electrically operated air pump must be supplied by its own generator which must be sited outside the living area of the shelter with its own ventilation and exhaust. It should be assumed that mains electricity will not be available.

(f) Air flow rate gauge.

(g) Discharge (pressure relief) valve.

(h) Fixed piping to exhaust position.

A typical arrangement for an underground concrete shelter is shown in Chapter 7.

Air requirements

The fan or pump should be capable of delivering a minimum of 1.4 litres per second (3 cubic feet per minute) of air for each person in shelter against the resistance of the air inlet cowl, any filters and pipework with an allowance for possible increase at inlet cowl for partial blockage, filter resistance through dust build up and internal pressure being above atmospheric. It is advisable to install a fan or air pump of more than adequate capacity to avoid the necessity for continual operation. A fan with a capacity of 3 litres per second per person need be operated only 30 minutes in every hour. With the fan operating in a closed shelter the internal pressure should be at least 50 Pa (0.2 in wg) above atmospheric.

Operation of fan

The fan should be set in operation as soon as the shelter is occupied and the outside doors closed. It should be closed down immediately following attack to prevent the filters blocking due to the air following the blast wave being contaminated with dust particles both from the ground and from any falling buildings. ***These particles will not be radioactive.*** Similarly the ventilation should be shut down when the fallout is expected to arrive. This information would be given by radio. It may be necessary to shut down in the event of nearby external fires to prevent fumes entering the shelter.

There is a limit, however, to the length of time during which it is safe to shut down the ventilation. The determining factor is the build up of carbon dioxide in the atmosphere. A level of 4 per cent carbon dioxide is dangerous; a level of 2.5 per cent can be tolerated by healthy people for a short period (say half an hour to one hour); a more comfortable limit is 1.5 per cent. Formulae giving the time of shut down of ventilation from the volume of air space per person for a limit of 1.5 per cent, 2.5 per cent and 4.0 per cent carbon dioxide are given below. These assume that the people are resting and they are based on a carbon dioxide production rate of 0.017 cubic metres per person per hour (0.6 cubic feet/person/hour).

For 1.5% $\quad t = \frac{V}{N} \times \frac{1.5}{1.7}$

For 2.5% $\quad t = \frac{V}{N} \times \frac{2.5}{1.7}$

For 4.0% $\quad t = \frac{V}{N} \times \frac{4.0}{1.7}$

Where:

t is time in hours

V is the total volume of shelter in cubic metres

N is the number of people in the shelter

During the operation of the ventilation and on restarting the ventilation after a shut-down a check should be made on the air flow rate gauge to ensure adequate air supply. A drop in the air-flow rate whilst the fan is in operation will indicate a blockage, most probably at the air inlet cowl. In this event it will be necessary to leave the shelter to clear the air inlet taking precautions before leaving and re-entering (see section 1.1.7). If the air inlet cannot be cleared then it will be necessary to open the doors to the outside; in this case the occupants should keep as far from the door as possible and away from direct line of sight to the outside.

Humidity and comfort 1.2.3

At the minimum air flow rate to maintain safe levels of carbon dioxide the ventilation will not necessarily control the temperature and humidity. Portable gas- or paraffin-fired lighting and cooking should not be used in the shelter whilst in the closed down condition. They should only be used if the door can remain open safely and then be sited near to the open door or under the open hatch. Smoking in moderation may be safe if it is carried on near to the air extract vent whilst the ventilation is in operation.

Radio reception 1.2.4

For some days the only contact with the outside world will be by radio. Wartime broadcasting will be on the medium wave band or on VHF. Since radio reception in a shelter may be seriously attenuated it is essential to have a radio with an external aerial socket so that, if necessary, an aerial outside the shelter can be connected to the radio. Radio reception should be tested when the shelter is constructed or installed.

Toilet arrangements 1.2.5

Some form of chemical toilet will be necessary. This can conveniently be of the type used in caravans; some of these can be used for a number of days without producing unpleasant smells. At some point the contents of the toilet must be taken outside. This can be done quite safely if it is carried out quickly. Preferably the occupants should take turns with this to reduce the level of radiation doses received by any one individual.

1.2.6 Food and water storage

Advice is given elsewhere on the kinds of food which should be taken into the shelter. But in the shelter design provision must be made for food storage and most importantly, water storage. Water should be stored sufficient for at least 2½ litres (4 pints) per person per day for 14 days. This will allow a small amount for toilet and washing purposes. It can be stored in plastic containers and these can be in the least protected part of the shelter. Water and food do not become radioactive or dangerous by being exposed to radiation. They only become contaminated if the dust settles on the food or in the water.

1.2.7 Emergency exit

In large shelters, the provision of an emergency exit remote from the main entrance is essential. In small family shelters the provision of an emergency exit is of less value, since it can only be sited within a few metres of the main entrance. However, in designing a shelter there are several matters which might be considered to ensure, as far as possible, that exit from the shelter will be possible if debris is deposited outside (see section 1.1.5).

Canopy over the door. In cases where the entrance to the shelter is down a ramp, it should be possible to build a canopy over the entrance to the doorway to prevent debris blocking the door.

Sand filled tunnel. In a concrete shelter, a section of the wall remote from the entrance can be replaced by a metal plate or masonry. A tunnel to the surface beyond this can be filled with sand which could easily be removed to gain access to the outside. Such an alternative arrangement is indicated in the concrete shelter in Chapter 7 of this book.

Tools. Picks and shovels should be part of the shelter equipment. If no special emergency exit is arranged it is essential, in the case of a hatch cover entrance, to provide some means of lifting the shelter door by mechanical means in case it is covered by debris or branches of fallen trees.

1.2.8 Shelter entrance

This should be of the correct type to withstand the design overpressure of the shelter. Information on this is given in Chapter 3 of this book. The main blast door would always be outward opening to ensure that the blast overpressure is more safely distributed across the entrance. Provision should be made for the removal of this blast door from the inside to aid escape.

If there is sufficient space it is worthwhile considering the provision of a ramped entrance to the shelter rather than a hatch cover and ladder. This will make entrance and exit easier for the elderly and incapacitated.

1.2.9 Interior fitments and decor

In purpose-built shelters (which are not inexpensive) it will be worthwhile considering the types of fitments and colours to avoid a universal drabness. This might be achieved by some form of light colours on the walls or even posters, a familiar carpet on the floor, etc. White or light coloured walls will also have the advantage of reducing the intensity of light required in the shelters.

Interior light can be supplied by batteries. These can be dry batteries or a car battery, fully charged before being taken into the shelter. Battery-powered fluorescent lighting is now available and this is more efficient in terms of battery life.

Originator and Reference	Security Classification	Title
C.D.E.E. Porton Tech. Paper (R)16 Nov. 1958.	Confidential	Radiological Decontamination: Removal of Dry Fallout from Skin and Clothing. E. Neale and Elizabeth H. Letts.
13th Tripartite Tox. Conf. Sept. 1958. Admiralty Paper DPR/BWS/144/58	Confidential	Contamination by Radioactive Fission Products. Acceptable Levels of Personal Contamination under Exceptional Circumstances. B. W. Soole.

13th Tripartite Tox. Conf. Sept. 1958. Admiralty Paper DPR/BWS/143/58	Confidential	A Comparison of the Internal and External Radiation Hazards to a Man Exposed to a Cloud of Fission Products from a Nuclear Explosion. B. W. Soole.
13th Trip. Conf. on Tox. Warfare Paper TCR7/58	Confidential	The relative Importance of External and Inhalation Hazards to Personnel in Fallout Areas and in Aircraft. J. K. Jones.
13th Trip, Conf. on Tox. Warfare Paper TCR2/58.	Confidential	Suggested Wartime Doses of Ionizing Radiation for Home Defence Purposes. Stanbury.
Tripartite Conf. Nov. 1955 Paper TC7/55	Unclassified	Contamination of Wounds with Fallout from Nuclear Weapons. Barnes and Loutit.

Classification of shelters 1.3

Summary of effects of nuclear weapons 1.3.1

From this brief review of the effects of nuclear weapons we can list the order of events from the detonation of a weapon. These are:

(a) Light and heat flash – immediate, and lasting some seconds.

(b) Initial nuclear radiation – following within one second of the commencement of the light flash.

(c) Blast wave – following from about a half second to several seconds after the light and heat flash.

(d) Fires – these may have been ignited by the heat flash but would be either extinguished or increased in intensity by the wind from the blast wave.

(e) Fallout – about one half hour to several hours after burst.

Protection against all these effects can be summed up by stating that distance from the source of the hazard and density of shielding materials give the best, and indeed the only, means of avoiding serious injury or death. The two major hazards in this list are blast and radiation. Adequate protection against these two will include protection against the others. It can indeed be said that adequate protection against blast will usually involve protection against radiation. The reverse however is not true. In spite of this, however, it is worthwhile looking at the need for protection in the whole of the United Kingdom.

Considerations arising from the probable attack pattern 1.3.2

In section 1.1.1 reference was made to the fact that an expected attack pattern on the United Kingdom might use 200 megatons on about 80 targets. If we now make an assumption that this attack would be in the form of 100 weapons of 1 MT airbursts and 100 weapons of 1 MT groundbursts we can use the information given in Fig. 6 to indicate the probability of areas being subject to various effects.

On this assumption, we should find that about 2.2 per cent of the land area of the UK would be subject to overpressures in the 'A' ring of 77 kPa (11 psi) and above about 1.8 per cent would be subject to overpressures of between 42 and 77 kPa (6-11 psi) in the 'B' ring and about 10 per cent of the land area would be subject to overpressures of between 10 and 42 kPa (1.5 to 6 psi). The rest of the land area, about 85 per cent, would be subject to blast in the D ring of 5 to 10 kPa (0.75 to 1.5 psi) or to no blast at all. Blast effects in the D ring will cause minor damage to buildings and no lethalities. It is impossible to determine the extent of the total D ring areas since many of these will overlap from adjacent bombs. Any part of the country might be subject to radiation from fallout.

There is of course no certainty of where the weapons will fall – and city centres are not necessarily the prime targets – but this consideration leads us to group shelters into various types and assess the probability of survival in given circumstances. It should of course be obvious that within about 450 metres (1500 feet) of a 1 MT groundburst no shelter can give any hope of protection. But the following grouping of shelters has some cogency.

U.K. Reports — DAMAGE TO TARGETS IN GENERAL: Thermal Radiation Damage and Fire Storms

No.	Originator and Reference	Security Classification	Title
1	S.A. Br. Home Office CD/SA6 (CD/3090)	Secret	The Atomic Bomb as A Fire Raiser. A study of the Mechanism of Initiation and Development.

U.S. Reports — DAMAGE TO TARGETS IN GENERAL: Thermal Radiation Damage and Fire Storms

No.	Originator and Reference	Security Classification	Title
1	U.S.A.Department of Agriculture Report AFSWP-413. Home Office Ref. CD.7384. (M.O.D.Ref. No.26).	Unclassified	Primary Ignitions following Atomic Attack on Urban Targets (Transient Exterior Fuels. 1953).
2	U.S.A. Department of Agriculture, Report AFSWP-412. Home Office Ref. CD.7385. (M.O.D.Ref. No.28).	Unclassified	Distribution of Primary Ignition Points following Attack on Urban Targets. (Transient Exterior Fuels. 1953).

A.F.S.W.P. Report WT-774 (M.O.D.Ref.No.77).	Confidential/ Atomic	Operation Upshot-Knothole, Project 8.11A, Incendiary Effects of Building and Interior Kindling Fuels, 1953.

A.W.R.E. Report T57/58	Unclassified	Operation Buffalo. Biology Group. Part 5. The Entry of Fission Products Into Food Chains.

Fig. 13 *Classification of shelters*

	Type 1 Improvised	Type 2 Indoor Kit	Type 3 Outdoor Kit	Type 4 Purpose built
Blast ** protection kPa (psi)	Up to 10 (1.5) (MODERATE, NOT SEVERE, DAMAGE: SURVIVAL OCCURS AT HIGHER PRESSURES)	Up to 42 (6)	Up to 77 (11)	In excess of 77 (11)
Fallout radiation protection	Not less than 40	Not less than 70	Not less than 200	In excess of 300. This type must also protect against INR
'Safety ** distance' from 1 MT airburst km (miles)	11.5 (7) (MODERATE NOT SEVERE EFFECTS TO SHELTERS!)	5 (3)	3.3 (2)	3.3 (2) for 77 kPa (11 psi) 3 (1.8) for 105 kPa (15 psi) 2 (1.2) for 315 kPa (45 psi) shelter
Ventilation	Natural	Natural or forced	Forced	Forced
Site of installation	In house† or garden	In house	In garden. Sectional for access through house	In garden. Appropriate access to garden necessary (See 1.3.4)
Forethought and planning	During crisis period. Some materials can be prepared in advance	Obtain in peace-time. Install in crisis period	Obtain in peace-time. Install in peace-time or crisis period. (2-3 days needed for installation (see 6.5)	Install in peace-time using professional advice and help.
Habitability	Not very comfortable. Suitable for few days occupancy. May be damp. Floor covering desirable	Able to sit up but not stand. May be able to use parts of house depending on radiation and damage situation	Rather cramped for 6 people; advance planning can improve comfort	Can be made very comfortable and habitable
Approximate expected cost (1980 prices)	Nominal if local materials used. Scaffold frame about £250	Kit: £500–£800 Bricks: £300	Kit: £900–£1800 Plus installation costs*	£6000–£10,000

*Installation costs will vary with nature of soil and nature of access to garden.
†E.g. The measures described in *Protect and Survive*.

** these blast criteria are for repeated nuclear explosion survival; nuclear tests showed shelters survived / allowed people to survive, at much greater pressures! See declassified reports appended at end.

Classification of shelters

Fig. 13 gives a convenient classification of shelters based on the 'damage rings' given in Fig. 6. The following notes must be read in conjunction with the table.

Shelter types and blast protection

This classification is based on the type of design and where the shelter can be used. These have a bearing on the blast overpressure which the shelter can withstand. Type 1 is a 'fallout shelter' but occupants will survive in such a shelter in areas where the blast overpressure is about 10 kPa (1.5 psi) or even greater. Such a type of shelter could make the difference between life and death for occupants in many areas in the country by giving protection against fallout radiation. The other types will give blast protection in rings 'C', 'B' and 'A'.

Radiation protection

The subject of radiation doses will be discussed in the section on shelter strategy later. Quite obviously the less radiation the body receives the better. But if one considers an area where the exposure-rate seven hours after bomb burst is 300 roentgens per hour, the total exposure at that point, assuming fallout arrives one hour after burst, during the succeeding 14 days would be approximately 10,000 roentgens. Anyone in a structure giving a radiation protective factor of 40 during this period would receive a dose of about 250 rads. This dose received over that period of time is one from which the body can recover with few, if any, immediate effects. Thus the life-saving and injury-minimising potential of shelters of Types 1 and 2 should not be under-estimated.

'Safety distance'

This column indicates the distance from ground zero of a 1 MT airburst beyond which shelters of given types would not suffer serious damage and the occupants would not suffer any significant injury. This subject is dealt with in more detail later in the section on the specific Home Office shelters. It should be noted that these distances represent the 'worst case'.

Ventilation

The subject of ventilation and filtration of air supplies has been dealt with in 1.2. This column is intended to indicate that shelters designed to give protection against radiation and possibly low values of blast overpressures can use natural ventilation. If the structure is intended to protect against high blast overpressures, then it is necessary to provide the structure with a sealed door and forced ventilation.

Site of installation

These comments refer to the Home Office designs. They do, however, draw attention to the fact that it is necessary to design shelters for houses with no access to the back garden except through the house, and for houses which have no back garden or none suitable for erection of a shelter.

Mode of installation

Reference to Chapter 4 of this book will indicate that Type 1 shelters can be installed on a DIY basis. It may be that help would be available from neighbours if households do not have the requisite able-bodied persons available. It will take two people 24 working hours to complete.

Types 2 and 3 are intended to be obtained in advance and stored until such times that advice is given for precautions to be taken. Type 2 can be put together in two hours by two people. Type 3 will take longer since a certain amount of excavation must take place in the garden before the shelter can be installed. This may take two to three days depending on the help available. Additionally, Type 3 can be installed in peace-time and can be semi-sunk, sunk, or sunk and covered with a concrete slab. This could result in giving protection against higher blast overpressures. However, in some areas ground water problems might be encountered if there is an attempt to completely bury the shelter.

Approximate cost

All the shelters described later in this book have been erected by Home Office staff. In the case of Types 2 and 3, the costs are based on the production of the components by private firms under contract. In the case of Type 4, these are based on calculations

followed by installation by a contract firm. Type 1 shelters have been erected at nominal cost, with the exception of the scaffold frame shelter. However, since the scaffold frame will have been purchased with its peace-time use in mind, the cost of such a shelter can also be considered nominal.

1.3.4 Further comments on Home Office shelter designs

Chapters 4 to 7 of this book give details of the Home Office shelter designs and, where appropriate, detailed instructions for construction. It will be useful however to discuss here the reasons why this range of shelters has been chosen. Other designs are under consideration and it is planned to make details of these available later.

Limitations related to houses and gardens

In making recommendations for shelters it has been necessary to keep in mind the varying needs governed by the types of housing in the United Kingdom. Very roughly housing can be divided into the following groups:

a. Detached or semi-detached houses where there is appropriate access to the rear garden. (About 34%).
b. Semi-detached and terrace housing where there is no access to the rear garden, except through the house. (About 20%).
c. Houses with no rear garden. Such houses usually have a passage between the rows of terraces with access to a back yard. (About 25%).
d. Multi-storey blocks of flats. (About 12%).
e. Flats resulting from the conversion of 2, 3 and 4 storey houses. There is usually some garden space available attached to such property. (About 7%).
f. Bungalows, usually with accessible gardens. (About 2%).
g. Caravans.

The shelter types in Fig. 13 are designed for use in these housing groups as follows:

Type 1 Groups a, b, c, f, possibly d, e and g.
Type 2 Groups a, b, c, f, possibly d.
Type 3 Groups a, b, f, possibly e.
Type 4 Groups a and f.

It will be seen that all groups of housing are covered except possibly for d and only minimally for e and g. Further consideration will be given to shelter provision for those in group d and also upper storeys of group e. However, we believe that one or more of our shelter types will be suitable for installation in the majority of the houses in the country.

Type 1 shelters

A 'core shelter' for use inside a house has already been described in ***Protect and Survive.*** Its life-saving potential should not be minimised. The details of the two improvised shelters in Fig. 13 are given in later chapters. The construction of these shelters has been carried out by volunteers satisfactorily. They were given a short time to read the instructions before carrying out the work. Although these are all designated improvised shelters, some thought can be given in advance to the procurement of materials for their construction, thereby eliminating the need to remove doors, etc. from the house.

Type 2 shelters

This type is designed for houses where there is no suitable ground attached to the house on which to install a shelter. It is in essence a 'core shelter' which will protect the occupants from the debris of a house that is severely damaged. The radiation protection factor is obtained by shielding it with bricks, blocks, sand, furniture, books, bags of soil, etc. It is designed to withstand the debris from a two- or three-storey house falling on it. However, it is probable that the debris from a three-storey house may make it difficult for the occupants to dig themselves out. The 'blast protection' indicated is that at which most houses would receive irreparable damage and there would be a considerable amount of debris on the shelter.

The details of this shelter are given in Chapter 5. This is not the only possible shape; further studies are underway which should result in different designs of the 'Indoor kit-type' shelter.

Type 3 shelters

The special feature of these types are: they are sectional and so can be taken through the house; they can be assembled on site, and so the 'handy-man' may be able to install them, so reducing cost; being sectional they can be stored in a garage or outhouse until required for use; they will give good protection even if semi-sunk, thereby eliminating the problems of high water table and disposal of the excavated earth, which can be used to cover the exposed portion of the shelter.

Considerably greater blast protection can be given by these shelters if they are completely sunk and especially if covered with a concrete slab. Some modification of the entrance would be required in this case. Details of a shelter of this type are given in Chapter 6.

Type 4 shelters

Chapter 7 gives details of a concrete shelter of this type. However, shelters made of other materials (such as steel, GRP, blockwork, etc.) and of other shapes (spherical, ovoid, etc.) come within this type if they give the required blast protection. Protection against blast overpressures of up to 315 kPa (45 psi) are considered, but such shelters must also be designed to protect against some INR. Advice on the structural design of such shelters is given in Chapter 3.

It will be clear that shelters of this type will need access to the rear garden and also that they are expensive, almost certainly costing at least £1000 per shelter space.

1957 Tripartite Conf. A.W.R.E. Report O-35/56(X)	Official Use Only	Dose rates from Ground Contaminated with Residual Radioactive Materials from an Atomic Explosion.

U.K. Reports — PERSONNEL, ANIMALS AND VEGETATION: Damage by Combined Effects

CONFIDENTIAL/DISCREET

No.	Originator and Reference	Security Classification	Title
1	Home Office (CD.9582)	Secret/U.K. Eyes	Casualty Rates for Ground Burst 10 Megaton Bombs, October, 1956.
2	A.W.R.E. T18/57	Confidential	Operation Buffalo: Target Response, Interim Report, Biology Group.
3	A.W.R.E. T18/54	Official use only	Hurricane Part 43. Trial carried out for Ministry of Food.
4	A.W.R.E. T44/54	Confidential	Summary Report on Biological Experiments.
5	D.T.S.D. Admiralty Part III of "Atomic Bomb Trials" (Op.Crossroads) CD.2122.	Top Secret	Biological Effects in the Bikini Atomic Bomb Trials.
6	A.O.R.G. Memo E.1.		Ready Reckoner for Atomic Casualties.
7	B.A.O.R. Operational Research Section Report 3/56.	Confidential	Effects of Atomic Weapons on Forests in North West Europe.
8	A .O.R.G. Report No.12/55	Secret/U.K. Eyes Only	The Protective Value to Personnel of Slit Trenches against Thermal and Gamma Radiation Effects of Nuclear Explosions.

Originator and Reference	Security Classification	Title
Army Operational Research Group A.O.R.G. Report No. 6/57	Secret	Mortality Rates from Nuclear Weapon Attacks. Hand N. E., Strong E. D., and Heritage K. J.

A.F.S.W.P. Report WT-1179	Official Use Only	Operation Teapot, Project 33.1. Biological Effects of Pressure Phenomena occurring inside Protective Shelters following Nuclear Detonation.
A.F.S.W.P. Report ITR-1507	Official Use Only	Operation Plumbbob, Project 33.6. The Internal Environment of Underground Structures subject to Nuclear Blast. II. Effects on Mice located in Heavy Concret Shelters.

A.W.R.E. Report T3/58	Confidential	Operation Buffalo. Physiological Effects of Long Duration Blast Waves. Krohn and McGregor.
A.W.R.E. Report T2/59	Confidential	Operation Buffalo. Biology Group. Part 3.A. The Effects of Blast on Dummy Men Exposed in the Open.

U.S. Navy Material Lab. Reports, Proj.5046-3		Part 39, May, 1954. The Temperature Rise of a Physical Skin Simulant behind an Irradiated Cloth Barrier.

Originator and Reference	Security Classification	Title
Johns Hopkins University ORO-T-1	Secret/Atomic	Thermal Screening by Foliage is described in Report 3 of Section 3.1 page A.1.
Wright Air Dev. Centre WADC TR-58-232 Oct. 1958	Unclassified	Visual Recovery Times from High-Intensity Flashes of Light. Metcalf and Horn.
Army Operational Res. Group 11/56 (CD.9656)	Confidential	Visual Incapacity Following Exposure to a Nuclear Explosion: Flash Blindness, September, 1956.
U.S.N./R.D.L. Report 394. (M.O.D. Ref. No.111)	Confidential/ Discreet	Ratio of Lung Beta to Whole Body Dose during given Time Intervals after an Atomic Bomb Detonation.

1.4 Shelter strategy for survival

1.4.1 Immediate post-attack

The possibility of surviving the immediate effects of a nuclear attack will depend upon a number of factors such as the pattern of attack, the weight of attack and the shelter posture of the population. Comments and advice have been given on these matters in earlier sections. The purpose of this section is to consider what procedures can be adopted by the survivors to increase their chances of survival under fallout conditions.

In the booklet *Protect and Survive* on pages 20 and 21 information and advice is given on what to do after the attack. This advice is written particularly for those who will be occupying a core shelter in their home; it is equally applicable to any who are occupying Type 1 and Type 2 shelters.

Those occupying Type 3 and Type 4 shelters should also study that advice. There will be a shorter or longer period after attack before the fallout begins to arrive and it will be worthwhile to emerge from the sealed shelter to check the situation outside. For example, small fires might be easily extinguished, which if allowed to burn could produce toxic fumes which might be drawn into the sealed shelter ventilation.

However, immediately on hearing a fallout warning it is essential to take cover in your shelter. You may hear the fallout warning without having heard an explosion.

1.4.2 Survival under fallout conditions

It is important to remember that only in the most contaminated areas will it be necessary to stay in the shelter for two weeks. Calculations based on weapon trials suggest that the most highly contaminated areas would have a dose-rate, seven hours after burst, of 400 roentgens per hour. By the end of two weeks this will have decayed to 4 roentgens per hour.

Advice has already been given to local authorities on procedures that can be adopted in fallout conditions. When the intensity of the radiation has fallen to certain levels, it will be possible for people to emerge from their shelters for one hour per day at first, then as the radiation intensity levels fall further, these periods of emergence from shelter can be increased in length until it will be possible to leave the shelter completely. These procedures are based on advice which has been received from the medical authorities on the ability of the human body to recover from certain levels of radiation doses. The times of emergence from shelter are calculated so that these daily levels will not be exceeded.

On the pattern of attack outlined earlier in this book, it is very probable that some people will be able to emerge from their shelter almost immediately since they will be in a fallout free area; others would be able to emerge after two or three days for short periods. These facts have a bearing on shelter preparations.

1.4.3 Shelter procedures

These will vary to some extent with the type of shelter which is being used, and it will be helpful to review these procedures under the various types of shelters.

Type 1 shelters

Information on procedures to be adopted for those occupying core shelters as described in *Protect and Survive* is given in that booklet. For those occupying improvised shelters in the garden there are a few obvious modifications to that advice.

Supplies. In *Protect and Survive* it is suggested that these should be kept in the fallout room, but outside the core shelter. In the case of those occupying improvised garden shelters it will be useful to take as much into the shelter as possible and store the remainder nearby under some cover.

When it is possible to emerge from the shelter for a short period, it will then be possible to remove unwanted material from the shelter and bring in further supplies.

Moving back to the house. If the house remains in reasonable condition it will be worthwhile considering moving back to stay in the house either completely, or for periods in the day. Much will depend on the radiation levels and the protection against radiation that can be arranged in the house. Here again *Protect and Survive* can be used in the preparation of suitable places in the house. The radiation doses received during the few minutes journey from the improvised garden shelter to the house are not likely to be dangerous to health.

Type 2 shelters

The primary purpose of these shelters is to protect the occupants from the debris resulting from partial or complete collapse of the house. If the house does collapse, then the occupants should survive, and, moreover, the debris will give increased radiation protection. It will be necessary in these circumstances to ensure that the exit from the shelter is not blocked and to remove any debris which may be blocking the exit. When it is possible to emerge from the shelter for an hour, it may be worthwhile looking around the immediate area to see whether there are other premises which might offer better or more comfortable protection. Shelter occupants should listen to the radio for advice before trying to move any great distance since they will not know which areas have higher or lower radiation intensities.

The advice given in *Protect and Survive* applies almost exactly to occupants of this type of shelter. Some of the food supplies should be taken into the shelter; the remainder should be in a place with some protection against debris, say under the stairs.

Type 3 and Type 4 shelters

These shelters are designed for continous occupation for up to fourteen days, so that supplies should be already in the shelters. However it may be that the Type 3 will not be large enough to have held all the necessary supplies so that it may be necessary to emerge from the shelter to replenish supplies from a previously prepared 'dump'. If the house remains standing and in reasonable condition then part of the time out of the shelter can be used to improve its habitability (if necessary) to prepare for complete emergence from shelter.

One important point will apply to all sealed shelters. It has already been said that it will be unwise to use any form of gas or paraffin for cooking inside the shelter whilst it is sealed. Once it is possible to open up the shelter — usually after a few days — it will be possible either to use gas to cook near the door of the shelter, or to use such stoves to cook in the house, using the shelter meanwhile as 'home' until it is advisable to emerge from the shelter completely.

Agricultural Res. Cttee. AERE Report ARC/RBC.5	Official Use Only	Ingestion of Fallout by Grazing Animals. Scott Russel, et al.
U.S.N.R.D.L. Report TR-77, T.I.L. Ref.No. P.71298.	Unclassified	Uptake, Distribution and Retention of Fission Products in Tissues of Mice exposed to a Simulant of Fallout from a Nuclear Detonation. I. Simulant of Fallout from a Detonation under Seawater.

U.K. Reports   PERSONNEL, ANIMALS, AND VEGETATION: Nuclear Radiation, Contamination and Decontamination

CONFIDENTIAL/DISCREET

No.	Originator and Reference	Security Classification	Title
1	A.W.R.E. T11/57	Official Use Only	Operation Buffalo: The Dose Received at Various Parts of the Body by a Man Walking over Contaminated Ground.
2	Air Ministry Sc.2 Memo. 254	Top Secret Atomic U.K.E.O.	The Danger to Bombers from Radio-active Clouds over a Realistic Target Area.
3	Atomic Scientists Journal Vol.4, No.2, Nov.1954	Unclassified	Bikini Ash
4	Home Office (CD.7241)	Confidential U.K.Eyes Only	The Initial Gamma Radiation Hazard from Very Large Weapons.
5	M of Supply, A.E.R.E. (Feb.1952) HP/M31	Confidential	Estimation of Energy Tolerances for Fission Products in Air and Water.
6	M of Supply, A.E.R.E. HP/M23	Confidential	Energy Tolerance for Fission Products in Drinking Water.
7	The Listener 28th October, 1954	Unclassified	The Dangers of Radioactive Dust.
8	A.R.Laboratory (Jan.1950) Report N1/R.322	Secret/Discreet	Effect of Continued Exposure to Radiation from Decaying Fission Products.
9	A.E.R.E./H.O. HP/R/737 (CD/SA/23)	Unclassified	The Hazard from Inhaled Fission Products in Rescue Operations.

A.W.R.E. Report O.34/56	Official Use Only	The Ingestion of Food contaminated by Atomic Explosions.
A.W.R.E. Report T.65/57	Confidential	Operation Buffalo. Biology Group, Part IV(b), The Effects of Neutron and Gamma Irradiation upon Foodstuffs.
Medical Research Council H.M.S.O. Cmd.9780, June, 1956.	Unclassified	The Hazards to Man of Nuclear and Allied Radiations.
A.W.R.E. Report T4/57	Confidential	Decontamination of Radioactively Contaminated Drinking Water in the Field.
R.A.E. Tech.Memo.ARM/1728	Secret	Incapacitation of Aircrew by Irradiation.
Ministry of Supply, D.A.W. Plans Memo. XY/144/03	Secret	Capabilities of Aircrew after Irrediation by Counter-Weapons (Equipment Considerations).
A.W.R.E. Report H12/52	Official Use Only	The Penetration of Gamma Radiation through the Walls of a Slit Trench.
M.R.C./A.E.R.E. 1955		The Effects of Gamma on Animals. Loutit.

1.5 Shelter supplies

Reference should be made to *Protect and Survive* pages 12 to 17. The information and advice in the following paragraphs amplifies that in *Protect and Survive* and extends it, particularly with regard to purpose-built shelters or any shelter built in peace-time. The information on food and water has been supplied by the Ministry of Agriculture, Fisheries and Food.

1.5.1 Water

The 2½ litres (4 pints) of water per person per day given in section 1.2.6 should be regarded as a minimum. Two pints per head per day is essential for drinking, but more will be needed for sanitation etc. and should be stored, either in the shelter or close at hand. Gallon cider flagons (of which 28 would be required for a family of four for a fortnight) or polythene jerrycans are excellent for storing water. If they are rinsed out with bleach or sterilising solution first they will keep sweet. The containers should be kept closed and in the dark to prevent the growth of certain organisms. In shelters of Types 1 and 2, these containers should be kept close at hand, either in the house (apart from immediate needs) or in an outhouse or garage. Either of these would produce less debris if damaged than would the collapse of the house. In the Type 3 shelter there would be some space for water storage, particularly in the entrance, but extra supplies can be stored close by outside. It is important to realise that water (and food, too) which is covered and exposed to radiation does not become dangerous to eat. Indeed it does not undergo any change at the levels of radiation being considered here.

In Type 4 shelters, consideration should be given to purpose-built storage systems for water fitted with a hand pump to make it available for use. Some shelters with floors over a curved base can make use of the dead space for water storage. In all such cases care must be taken to drain and refill the tank at regular intervals to prevent the growth of algae or other organisms. Attempts to keep the water as pure as possible are essential, particularly during the first few days when boiling it may not be possible.

1.5.2 Food

The lists of foods given in Fig. 14 will give a reasonable mixed diet for two weeks.

The following points should be noted:

The best foods for this situation are those which are tinned, packaged or, if water storage presents no problem, dehydrated. They should be kept cool and dry.

These examples have been chosen because they store relatively easily, keep a long time without refrigeration, are easily prepared and require little or no cooking. If no source of heat is available they can, with the exception of tea and coffee, be eaten raw.

Calorie intake

This basic diet would provide about 2000 calories per day — ample for preserving life, especially under shelter conditions with little need for physical activity. The current average daily intake is 2250 calories per person (more for adults, especially men, but less for children and some women).

Infants

These should have dried infant formula, or alternatively 7 kg full cream evaporated milk and ½ kg sugar or 2½ kg full cream dried milk and ½ kg sugar for a fortnight. If the infant is breast fed then the mother will need supplementary food. As the infant is weaned from 3-4 months onwards baby foods or mashed adult foods should gradually replace some of the milk feeds. Some form of battery operated heating equipment is necessary to facilitate the warming of feeding bottles.

Children under five

Between the ages of six months and one year an infant will be eating progressively more 'adult' foods until at one year old a shelter stock half that for an adult should be included to take account of his requirements. Children aged from one to five years should be counted as half an adult and each would need, in addition, 8 large tins of evaporated milk, or 3 x 300 g containers of dried milk.

Fig. 14 ***Suggested food stocks for two weeks***

Item	For one person
Biscuits, crackers, breakfast cereals etc.	2750 g
Tinned meat or fish (e.g. tinned beef, luncheon meat, stewed steak, pilchards, sardines)	2000 g
Tinned vegetables (e.g. baked beans, carrots, potatoes, sweetcorn etc.)	1800 g
Tinned margarine or butter, or peanut butter	500 g
Jam, marmalade, honey or spread	500 g
Tinned soups	6 tins
Full cream evaporated milk (or dried milk)	14 small tins (2 x 300 g containers)
Sugar	700 g
Tea or coffee (instant)	250 g
Boiled sweets or other sweets	450 g
Tinned fruit, fruit juices, fruit squash, drinking chocolate	If sufficient storage space is available
Approximate cost (mid-1980)	£15–£20

Children over five and adults

It is best to concentrate on foods of high energy value: a normally healthy person can survive without a properly balanced diet for many weeks. Salty or highly spiced foods should be omitted during the 'lie-low' period as should salt itself. The greatly increased requirement for water which salt brings about would be extremely difficult, if not impossible, to satisfy with a limited water supply. No adverse effects will result from the exclusion of salt from the shelter diet.

Variety in foods

The list in Fig. 14 should not be regarded as a hard and fast shopping list. It is important to remember that favourite or familiar foods will be important psychologically. There is room for flexibility both within and between groups of foods. Fats could be decreased by 250 g and cereals increased by 450 g; or 350 g of tinned meat could be substituted for the boiled sweets. If storage space is limited then the tinned fruit and fruit juices can be omitted but these items do increase the variety of the diet and provide some liquid intake.

Turnover of food stocks

If a regular stock or emergency supply of food is to be kept it is necessary to replace all tinned goods at least once every two years using and replacing the oldest stocks first (those containing acid fruits like tomatoes or pineapple, and evaporated milks, will only be at their best for about six months). Packeted foods should be replaced at least every six months. Cereals should not be kept for very long periods and their storage life is approximately four to six months. Biscuits and similiar items should be kept in a metal container.

Use of perishable foods

When an attack appears imminent perishable foods including those in freezers and refrigerators should be eaten first, and other household stocks reserved for the emergency store. When the electricity supply ceases, food in freezers will gradually thaw and then deteriorate; nevertheless it and other perishable items can make a useful addition to the diet for the first few days in the shelter.

1.5.3 Tools

In Type 3 and Type 4 shelters, particularly those sited below ground it is especially important that tools be stored in the shelter to enable the occupants to dig themselves out should occasion arise. A pick and spade are essential; in the case of a trap door entrance, some form of lifting gear would be desirable in case debris or tree branches have fallen over the entrance.

In the Type 2 shelters a spade would be essential in case of house collapse onto the shelter. This might also apply in the case of the *Protect and Survive* core shelter.

1.5.4 Other supplies

A study should be made of the contents of *Protect and Survive,* particularly pages 14 to 17. The supplies there may need to be adapted to the particular form of shelter being stocked. But all the classes of items are important and so are listed here:

Portable radio (receiving medium wave) and spare batteries. A spare radio would be desirable. In the case of shelter Type 3 and Type 4 it is essential to have a radio with an aerial socket. A make-shift aerial can be fitted up passing to the outside of the shelter. A socket on the radio is then necessary to receive the connection to the aerial.

Tin opener, bottle opener, cutlery and crockery.

Warm clothing, and changes of clothing.

Bedding, sleeping bags, etc.

Saucepans, food containers.

Torches with spare bulbs and batteries.

Toilet articles, toilet rolls, plastic buckets.

Overalls or an outdoor coat which can be left near the shelter entrance in case you have to go outside the shelter.

First aid kit and simple remedies.

Box of dry sand, cloths or tissues for wiping plates and utensils.

Notebooks and pencils.

Games, toys, magazines.

Clock (mechanical) and calendar.

Sanitation supplies such as polythene bag linings, strong disinfectant.

Two dustbins or buckets, one for temporary storage of sealed bags of waste matter and one for food remains, empty tins and rubbish.

Home Office Report CD/SA.71	Confidential	Numbers of Casualties from a Ground Burst Megaton Weapon Likely to be Personally Contaminated by Radioactive Material. E. C. Allen
A.W.R.E. Report T64/57	Confidential	Operation Buffalo. Effects of an Atomic Explosion on Medical Supplies.
C.D.E.E. Porton Tech. Paper (R)15 4th March, 1959.	Restricted	Production of a Simulant for Radioactive Fallout.
Home Office Scientific Adviser's Branch Report CD/SA.89 Oct.1958	Restricted	Survey of the Protection Afforded in Private Houses against Radiation from Fallout. D.T. Jones.
A.W.R.E. Report No. T37/58	Secret/Atomic U.K. Eyes Only	Operation Antler. The Shielding from Initial Radiation Afforded by Soil.
C.D.E.E. Porton Tech. Paper (R)20 9th April, 1959.	Confidential	Fallout Leaching Studies.

Planning permission, Building Regulations and rating

If a permanently installed shelter is to be used in peace-time the precise nature of that use will influence any exemptions available. Anyone proposing to erect a shelter should first consult their local authority specifying any intended alternative use and enquiring what special arrangements, if any, are necessary for land and surface water drainage.

Schedule 1 to the Town and Country Planning General Development Order 1977* (Statutory Instrument 1977 No 289), sets out types of permitted development which may be undertaken without the need to make a planning application to the planning authority. Shelters built within the curtilageø of a dwelling house may come within this, if they meet the requirements of class 1 of Schedule 1 to the General Development Order. Whether or not any particular development proposal would require express planning permission would be a matter for the planning authority to decide in the first instance.

In England and Wales, the Building Regulations do not apply provided a shelter is completely detached from any other building and is not so erected as to adversely affect the stability of neighbouring buildings. In addition it must not be connected to drains serving another building and must be used solely as a nulcear shelter. If these requirements are not satisfied, then Building Regulations will still apply. In Scotland, a building warrant will normally be required and the local authority will be able to advise on this and on any relaxation of regulation requirements which may be necessary.

In England and Wales, the provisions of Section 46 of the General Rate Act 1967 apply to nuclear shelters. These provisions are likely to give relief from rating to shelters provided they are not put to any other use. When the alternative use is considered to be minimal, relief may still be granted. Whether or not to grant relief from rating is a matter for your local District Valuer and Valuation Officer. There is the right of appeal to the Local Valuation Panel. In Scotland, the Rating and Valuation (Air-Raid Works) (Scotland) Act 1938, as amended, provides that no rating liability will attach to shelters provided they are not put to any other use. It is for the local Assessor to decide what value, if any, should be put on a shelter; in the event of disagreement with his decision, the matter may be discussed with him and, if that does not resolve the difficulty, an appeal can be made to the local Valuation Appeal Committee.

N.A.T.O. (CD.9643)	Confidential	The Vulnerability of Dock Gates Subjected to Atomic Attack.

U.K. Reports. DAMAGE TO NAVAL AND MARITIME STRUCTURES. Nuclear Radiation, Contamination and Decontamination.

No.	Originator and Reference	Security Classification	Title
1	Admiralty Research Lab. Report R2/C.747.	Confidential	Evaluatibn of the Washdown Effectiveness of a Ship's Pre-wetting.
2	A.W.R.E. T109/54	Confidential/ Atomic	Radiochemical Decontamination Experiments on Naval Construction Materials I. Evaluation of Pre-wetting.
3	A.W.R.E. T110/54	Confidential	Radiochemical Decontamination Experiments on Naval Construction Materials II. Experiments on Contaminated Dry Samples.
4	1957 Tripartite Conf. Report AWEC/P(57)215.	Secret	The Protection Afforded by a Ship's Structure against the Gamma Radiation emitted by an Atomic Explosion.

U.K. Reports. DAMAGE TO NAVAL AND MARITIME STRUCTURES. Damage by Blast and Water Waves.

No.	Originator and Reference	Security Classification	Title
1	Atomic Bomb Trials (Operation Cross Roads) Parts 1 and 2. C.B.004467A and Annexures C.B.004467B. 1946.	Secret	Report of the British Services Observer at Bikini Atoll.
2	N.C.R.E. Report No.R.330	Secret	Some Experiments on Ships' Funnel Models subjected to Air Blast Loading, May, 1957.
3	Cole, R.H.	Unclassified	Underwater Explosions (Book)
4	A.R.E. Report 1/48. January, 1948.	Secret	The Physical Effects of Atomic Weapons, Part 1. Damage to Ships of Underwater Explosions of Atomic Bombs. Penney.

Home Office Report CD/SA51	Confidential	Assumed Effects of Two Atomic Bomb Explosions in Shallow Watter Off the Port of Liverpool.

Admiralty ARL/R1/AW 50	Secret/Discreet	The effect of a 10 magaton Weapon on a Fleet at Anchor in Scapa Flow.

*In Scotland Schedule 1 to the Town and Country Planning (General Development) (Scotland) Order 1975 (Statutory Instrument 1975 No. 679).

ø'Curtilage': the area attached to a dwelling house as part of its enclosure.

No.	Originator and Reference	Security Classification	Title
1	U.S. Chem.Corps CRLR.326 (CD.7081)	Confidential/ Discreet	Interim Report. Experimental-theoretical Attenuation of 1.2 Mev Gamma Radiation by Simple Structures.

Chapter 2

Calculation of protective factors

Most of the fallout derived from the fission products of a ground-burst nuclear weapon is deposited over a large area and buildings or shelters located in this area will be covered with fallout particles. Fallout which is deposited within 24 hours after attack measures between about 20 and 700 microns (thousandths of a millimetre) and if buildings are undamaged and windows and doors are closed only a small proportion of the particles will penetrate into the building. This proportion can be regarded as negligible.

Particles of less than 20 microns would be carried by the wind to much greater distances and might not be deposited for many weeks or possibly months. By that time the radioactivity would have decayed several thousand-fold and individual particles would have become so widely dispersed in the atmosphere that they no longer represent any significant fallout hazard when they are finally deposited.

Since gamma radiation emitted from fallout can penetrate into buildings it poses a very serious threat to the maintenance of life after attack. However, buildings offer protection to individuals sheltering within by reducing the intensity of this radiation. The reduction comes about for two reasons. Firstly, radiation intensity is attenuated by the weight or density of material which lies between the source and the individual in question. Secondly, the gamma dose-rate received by a person depends on his distance from the source of radiation. The radiation received from a point source (fallout is not a point source) is inversely proportional to the square of the distance from the source such that, for example, doubling the distance reduces the dose-rate by a factor of four. Although both parameters, size and mass, are effective it is the mass (per unit area of material) of the building which is usually the more significant in attenuating the dose-rate from an external radiation field.

2.1 Definition of protective factor

The protection afforded by a building against the gamma radiation from fallout is expressed as the protective factor (PF) of the building; that is the factor by which the dose-rate received by a person inside the building is reduced as compared with that received by a person standing in the open on flat ground. Thus, if a building has a PF of 100 it means that the dose-rate inside the building is 1/100th of the dose-rate outside.

The system described in this chapter for the calculation of protective factors is based on joint USA/UK investigations into the protection offered by dwellings against ionising radiation. It is a simplified manual method for calculation. A computer program based on the data contained in this paper has been developed by Scientific Advisory Branch, Home Office. This program is known as PROTFAC.

2.2 Assumptions to the manual method for calculation of protective factors

Radiation from fallout is regarded as entering the building from five distinct plane sectors; one on the roof and four on the ground. Each of the five sectors is regarded as providing a separate contribution to the radiation intensity inside the building and each contribution is calculated as a percentage of the total intensity outside. The contributions are then summed to give the total percentage intensity inside and the reciprocal of this fraction is the protective factor.

In order to ease the problems of calculation a number of simplifying assumptions are made.

2.2.1 Distribution of fallout

It is assumed that:

i. Fallout is uniformly deposited on the ground and on the roof.

ii. There is no fallout deposited on the walls, window sills or other projections from walls.

iii. No fallout enters the building.

Reference	Classification	Title
Chemical Corps Chemical and Radiological Laboratories Report CRLR-326, 15th September, 1955,(M.O.D.Ref.No.82).	Confidential/ Discreet (C.C.)	Experimental-Theoretical Attenuation of 1.2 Mev. Gamma Radiation by Simple Structures.

2.2.2 Shape and size of building

The following assumptions are made for the building:

i. The roof is flat and at a height which is the average of the height to eaves and ridge.

ii. The calculation is made for a point one metre above the centre of the given floor level and the result assumed to hold good for the whole of that floor level. The position of one metre above floor level is chosen to represent the height of the mid-body line position of a person standing in the room. It also represents the point at which a radiac dose-rate meter would be held if used to determine the protective factor experimentally. The calculation procedure allows for variation in height to be made if it is assumed that occupants of a shelter would spend most of their time sitting or lying on the floor, i.e. below one metre above the ground level.

iii. Minor deviations in the shape of the building are not taken into account. Length and breadth are the basic values used in the calculation and are averaged, where necessary, to allow for irregularities.

2.2.3 Building materials and construction

i. Attenuation of radiation depends on the thickness and density of the material through which it passes. The basic quantity used is weight, expressed in kilograms per square metre (kg/m^2). In practice the walls and floors of a building are seldom of uniform thickness throughout and for the purposes of the calculation the variations in thickness are averaged. Precise weights of construction may be difficult to obtain but structural engineers and quantity surveyors would be able to estimate these weights with an accuracy more than adequate for the purpose of the calculation.

The thickness of material needed to reduce the dose-rate in a gamma beam by half is called the half-value thickness. Each successive half-value layer similarly reduces the dose-rate transmitted by half for weights up to about 700 kg/m^2. Fig. 15 shows the half-value thickness of common construction materials against residual gamma radiation. Thus a 5.6 cm thickness of concrete will reduce the dose-rate of residual radiation to one-half of its original value, 11.2 cm will reduce it to a quarter and so on. Brick walls of 11.5, 23.0 and 34.0 cm will reduce the intensity of radiation by factors of about 3, 10 and 30 respectively.

Fig. 16 describes weights of materials commonly used in construction with the values expressed in kg per square metre and per centimetre thickness. Since construction methods follow very similar patterns from building to building it is convenient to summarise types of wall, floor and roof construction into general categories (see Fig. 17).

Fig. 17 makes allowances for variations in construction methods such as load bearing walls made from bricks or bricks and blocks and for plaster coverings to the internal surfaces of walls. It also provides a useful guide to a first approximation for the assessment of weights of materials used in construction.

ii. In a building to be used as a shelter against fallout it is advantageous to screen doors and windows with material having the same weight (kg/m^2) as the surrounding wall. Calculated protective factors in buildings where openings are not screened are not as reliable as when openings are screened. In the unscreened cases the calculations give an average value for the protective factor; occupants having lines of sight to the outside have a lower protective factor than average and occupants without lines of sight have higher factors.

Fig. 15 ***Half-value thickness of shielding materials against residual gamma radiation***

Material	Half-value thickness mm.	(ins)	Material	Half-value thickness mm.	(ins)
Lead	13	(0.51)	Stone	56	(2.2)
Steel	18	(0.7)	Brickwork	71	(2.8)
Tiles	40–50	(1.6–2.0)	Earth	84	(3.3)
Asphalt	56	(2.2)	Plaster	85	(3.4)
Concrete	56	(2.2)	Wood	224	(8.8)

Fig. 16 ***Weights of common materials used in building construction***

Adapted from *Schedule of Weights of Building Materials* BS 648: 1964

Material	Weight in kg/m²/10mm	(lbs/ft²/in.)
Lead	114.0	(59.0)
Solid steel	78.5	(40.8)
Concrete: Natural aggregate	23.0	(12.0)
Lightweight aggregate	18.0	(9.2)
Stone: Light (Bath)	21.0	(11.0)
Medium (Portland)	22.0	(11.5)
Heavy (Marble)	27.0	(14.0)
Slate (slab)	29.0	(15.0)
Slating tiles: Welsh thin	24.0*	(5.0)*
thick	49.0*	(10.0)*
Westmorland thin	49.0*	(10.0)*
thick	78.0*	(16.0)*
Corrugated asbestos sheet:	17.0*	(3.5)*
Flat wallboard	10.5	(5.6)
Flat fully compressed	19.0	(10.0)
Asphalt—roofing quality	22.0	(11.5)
Brick: Solid medium density	21.5	(11.2)
Perforated medium density	18.5	(9.6)
Block clay medium density	11.0	(5.7)
Roof tiles: Clay: Interlocking single lap	39.0*	(8.0)*
Stone aggregate: Interlocking single lap	49.0*	(10.0)*
Wall tiles: Clay	20.5	(10.1)
Fibre	3.0	(1.5)
Polystyrene (expanded)	4.0	(2.1)
Sand	16.0	(8.4)
Soil (firm silt and clay)	17.5	(9.0)
Plaster	17.3	(9.0)
Plasterboard	9.0	(4.6)
Wood: Soft	4.8	(2.5)
Medium	6.7	(3.5)
Hard	7.2	(3.7)

*In standard thicknesses

Fig. 17 ***Weights of building materials in combined use***

Materials	Weight in kg/m^2 (lb/ft^2)
1. External walls	
(a) 275 mm (11 in.) cavity – 2 x 102-112 mm ($4\frac{1}{2}$ in.) brick skins + 12 mm ($\frac{1}{2}$ in.) plaster	510 (105)
(b) 275 mm (11 in.) cavity – 2 x 102-112 mm ($4\frac{1}{2}$ in.) brick skins + 19 mm ($\frac{3}{4}$ in.) plaster	525 (108)
(c) 275 mm (11 in.) cavity – 102-112 mm ($4\frac{1}{2}$ in.) brick outer skin, 100 mm (4 in.) concrete block inner skin + 12 mm ($\frac{1}{2}$ in.) plaster	420 (86)
(d) 275 mm (11 in.) cavity – 102-112 mm ($4\frac{1}{2}$ in.) brick outer skin, 100 mm (4 in.) concrete block inner skin + 19 mm ($\frac{3}{4}$ in.) plaster	430 (88)
(e) 225 mm (9 in.) solid brick + 12 mm ($\frac{1}{2}$ in.) plaster	510 (104)
(f) 225 mm (9 in.) solid brick + 19 mm ($\frac{3}{4}$ in.) plaster	525 (108)
(g) 350 mm (14 in.) solid brick + 19 mm ($\frac{3}{4}$ in.) plaster	800 (164)
(h) 450 mm (18 in.) solid brick + 19 mm ($\frac{3}{4}$ in.) plaster	1015 (208)
2. Internal walls	
(a) 102-112 mm ($4\frac{1}{2}$ in.) brick + 12 mm ($\frac{1}{2}$ in.) plastered both sides	290 (59)
(b) 102-112 mm ($4\frac{1}{2}$ in.) brick + 19 mm ($\frac{3}{4}$ in.) plastered both sides	310 (64)
(c) 100 mm (4 in.) concrete block + 12 mm ($\frac{1}{2}$in.) plastered both sides	200 (41)
(d) 100 mm (4 in.) timber stud + 12 mm ($\frac{1}{2}$ in.) plasterboard + 3 mm ($\frac{1}{8}$ in.) skim both sides	60 (12)
(e) 225 mm (9 in.) brick – 19 mm ($\frac{3}{4}$ in.) plastered both sides	560 (115)
(f) 63 mm ($2\frac{1}{2}$ in.) gypsum dry partition	25 (5)
3. Suspended upper floors	
(a) 25.4 mm (1 in.) T & G boards on 175 mm (7 in.) x 50 mm (2 in.) joists with 3 mm ($\frac{1}{8}$ in.) skim on 9 mm ($\frac{3}{8}$ in.) plaster-board ceiling	60 (12)
(b) 150 mm (6 in.) hollow clay block & concrete with 38 mm ($1\frac{1}{2}$ in.) screed and 12 mm ($\frac{1}{2}$ in.) plaster ceiling	270 (55)
(c) 150 mm (6 in.) solid reinforced concrete, with 38 mm ($1\frac{1}{2}$ in.) screed and 12 mm ($\frac{1}{2}$ in.) plaster ceiling	475 (97)
4. Flat roofs	
(a) 150 mm (6 in.) hollow clay block and concrete with 19 mm ($\frac{3}{4}$ in.) asphalt on 38 mm ($1\frac{1}{2}$ in.) screed and 12 mm ($\frac{1}{2}$ in.) plaster ceiling	320 (66)
(b) 150 mm (6 in.) solid reinforced concrete, with 19 mm ($\frac{3}{4}$ in.) asphalt on 38 mm ($1\frac{1}{2}$ in.) screed and 12 mm ($\frac{1}{2}$ in.) plaster ceiling	520 (107)
(c) 3-layer felt on 50 mm (2 in.) wood wool slabs on 175 mm (7 in.) x 50 mm (2 in.) joists and 3 mm ($\frac{1}{8}$ in.) skim on 9 mm ($\frac{3}{8}$ in.) plaster-board ceiling	70 (14)

Materials	Weight in kg/m^2 (lb/ft^2)
5. Pitched roofs	
(a) Timber framed + plain clay tiles on battens on felt	90 (18)
(b) Timber framed + slates to 75 mm (3 in.) gauge on battens on felt	60 (12)
6. Ceiling to pitched roofs	
(a) 3.2 mm (⅛ in.) skim on 9 mm (⅜ in.) plaster-board on 100 mm (4 in.) x 50 mm (2 in.) bearers	36 (7)
(b) 19 mm (¾ in.) plaster on 100 mm (4 in.) x 50 mm (2 in.) bearers	43 (9)

Fig. 18 ***Weights of miscellaneous individual materials***

Materials	Weight in kg/m^2 (lb/ft^2)	
Asbestos sheets (corrugated)	16	(3.0)
Stone paving: (50mm/2 ins thick)		
Natural stone	127	(26.0)
Artificial stone	122	(25.0)

Fig. 19 ***Weights of individual materials***

Materials	Weight in kg/m^2 (lb/ft^2)
102-112 mm (4½ in.) brick	245 (50)
225 mm (9 in.) brick	490 (100)
338 mm (13½ in.) brick	737 (150)
450 mm (18 in.) brick	982 (200)
100 mm (4 in.) concrete block	156 (32)
12 mm (½ in.) plaster	22 (4.5)
19 mm (¾ in.) plaster	33 (6.8)
19 mm (¾ in.) asphalt	42 (8.6)

Fig. 20 ***Weights of some other materials***

Materials	Weight in $kg/m^2/10mm$ $(lb/ft^2/in.)$	
Granite: medium	26.0	(14.0)
heavy	29.0	(15.5)
Marble	27.0	(14.0)
Portland Stone	22.0	(11.5)
Sandstone: light	22.0	(11.5)
heavy	24.0	(12.5)
Portland Cement	23.0	(12.0)
Concrete (not reinforced)	23.0	(12.0)
Soils: Sands & Gravel (loose)	18.5	(9.5)
Clays & Silts (dense)	20.0	(11.0)
(firm)	17.5	(9.0)
Glass	29.0	(15.5)

Method for the calculation of protective factors 2.3

Roof contribution 2.3.1

To find the roof contribution, the first step is to calculate the value for $\frac{\sqrt{A}}{H\text{-}x}$ where A is the area of the roof in square metres, H is the height in metres of the average roof level above the floor and x is the height in metres of the point above the floor. The next step is to estimate the weight of overhead material (roof and upper floors) in kg/m^2 of the floor area. The roof contribution can then be read from Fig. 21. For example, an ordinary semi-detached house might have a ground floor area of 46 square metres and a height of 6 metres; therefore, if $x = 1$, $\frac{\sqrt{A}}{H\text{-}x} = 1.4$. The weight of overhead material for such a building could be typically about 170 kg/m^2 and from Fig. 21 it is found that the roof contribution, by interpolation, is 3.12 per cent.

Some buildings have substantial internal partition walls which may modify the contribution from the roof. If the partition is less than 100 kg/m^2 the effect is ignored and if more than 300 kg/m^2 then the roof area is taken as that obtained by measurement up to the wall partition, provided that the internal wall partition extends up to the roof level. For internal wall weights between 100 kg/m^2 and 300 kg/m^2 the following calculation must be made:

a. Calculate the values for $\frac{\sqrt{A_t}}{H\text{-}x}$ and $\frac{\sqrt{A_r}}{H\text{-}x}$ where A_t is the total roof area and A_r is the roof area of the refuge room within the limits of the internal walls.

b. Find the roof contribution from Fig. 21 using $\frac{\sqrt{A_r}}{H\text{-}x}$ and the weight of overhead material.

c. Find the roof contribution from Fig. 21 using $\frac{\sqrt{A_t}}{H\text{-}x}$ and the summed weights of overhead material and internal wall.

d. Find the contribution from Fig. 21 using $\frac{\sqrt{A_r}}{H\text{-}x}$ and the summed weights of overhead material and internal wall.

e. Roof contribution R% = (b) + (c) − (d).

Wall contributions (above ground) 2.3.2

The contribution through each wall on the ground floor of a simple rectangular building can be obtained from Fig. 22 using the value of $\sqrt{A}$ and the weight of wall or walls on each of the four sides of the building.

However, this value may be subject to one or more corrections as follows:

1. The contribution for each wall is multiplied by factor of $\frac{4l}{P}$ where l is the length of each wall (metres) and P is the perimeter of the building. This correction allows for differences in length of walls of a building and the concomitant differences in radiation intensity through the mid-point of each wall area. Therefore, in a square building the multiplier would be unity.

2. Apertures such as unscreened windows and doors must be allowed for in the calculation of a wall contribution.

3. In more complicated cases the walls of a shelter room might be either external or internal (partition) walls and these two alternatives have to be allowed for in the calculation. However, where apertures occur only those in the immediate wall are taken for calculation. (An immediate wall is one immediately adjoining a shelter room. It can be either an external or internal wall.)

i. Contribution through an *external wall* of a shelter room. Contributions are calculated for each of the external walls of the shelter room in turn.

a. Calculate the wall contribution from Fig. 22 using $\sqrt{A}$ and the weight of the wall material.

b. If there are apertures in the wall calculate the wall contribution from Fig. 22 using $\sqrt{A}$ and 0 kg/m^2.

Fig. 21 ***Percentage penetration through a roof***

Percentage Penetration through a Roof

$\sqrt{\frac{A}{H-X}}$

Weight of overhead material kg/m^2

	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00
0.00	0.72	1.40	2.32	3.48	4.72	5.98	7.13	8.32	9.48	10.68	11.84	12.98	14.12	15.20	16.15	17.08	18.02	18.91	19.61	20.96	22.70	23.51	24.71	25.88	26.90	27.75	28.57	29.38	30.12
25.00	0.68	1.32	2.19	3.27	4.44	5.65	6.77	7.93	9.03	10.16	11.24	12.28	13.32	14.31	15.16	16.00	16.83	17.63	18.26	19.48	20.66	21.71	22.72	23.69	24.53	25.22	25.88	26.53	27.13
50.00	0.64	1.24	2.06	3.08	4.19	5.33	6.42	7.56	8.60	9.66	10.67	11.62	12.58	13.47	14.23	14.98	15.72	16.43	17.00	18.10	19.17	20.05	20.88	21.69	22.37	22.92	23.45	23.69	24.43
75.00	0.60	1.17	1.94	2.90	3.94	5.03	6.09	7.20	8.19	9.19	10.13	11.00	11.87	12.68	13.36	14.02	14.69	15.32	15.83	16.82	17.78	18.51	19.19	19.85	20.30	20.83	21.24	21.44	22.00
100.00	0.57	1.10	1.83	2.73	3.71	4.57	5.78	6.86	7.78	8.73	9.59	10.38	11.17	11.90	12.50	13.09	13.67	14.23	14.68	15.56	16.41	17.01	17.55	18.07	18.50	18.83	19.14	19.44	19.72
125.00	0.53	1.03	1.71	2.55	3.49	4.47	5.45	6.46	7.30	8.15	8.92	9.60	10.28	10.89	11.38	11.87	14.23	12.79	13.31	13.80	14.45	14.87	15.25	15.62	15.93	16.17	16.41	16.63	16.84
150.00	0.50	0.96	1.60	2.39	3.27	4.22	5.14	6.09	6.85	7.62	8.29	8.87	9.45	9.97	10.37	10.76	11.13	11.49	11.75	12.24	12.71	13.00	13.26	13.50	13.71	13.89	14.07	14.23	14.38
175.00	0.47	0.90	1.49	2.24	3.08	3.97	4.84	5.74	6.42	7.11	7.70	8.20	8.69	9.12	9.44	9.75	10.05	10.32	10.51	10.86	11.19	11.37	11.52	11.67	11.80	11.94	12.06	12.18	12.29
200.00	0.44	0.84	1.39	2.09	2.88	3.72	4.52	5.35	5.96	6.57	7.08	7.50	7.91	8.27	8.52	8.76	9.00	9.21	9.34	9.58	9.81	9.91	10.00	10.08	10.17	10.26	10.35	10.44	10.52
225.00	0.41	0.80	1.31	1.94	2.64	3.39	4.07	4.76	5.28	5.80	6.22	6.57	6.91	7.20	7.41	7.61	7.80	7.97	8.07	8.26	8.43	8.53	8.62	8.69	8.78	8.86	8.94	9.02	9.08
250.00	0.39	0.75	1.22	1.80	2.43	3.08	3.66	4.24	4.68	5.11	5.47	5.75	6.03	6.27	6.44	6.60	6.76	6.90	6.98	7.12	7.25	7.34	7.42	7.50	7.57	7.65	7.72	7.79	7.85
300.00	0.34	0.66	1.07	1.56	2.06	2.57	2.98	3.39	3.69	4.00	4.24	4.42	4.61	4.76	4.87	4.98	5.08	5.17	5.22	5.30	5.37	5.45	5.51	5.58	5.64	5.70	5.75	5.80	5.85
350.00	0.31	0.58	0.94	1.36	1.78	2.19	2.50	2.81	3.02	3.22	3.37	3.48	3.58	3.67	3.73	3.79	3.85	3.90	3.93	3.98	4.02	4.06	4.11	4.15	4.19	4.23	4.27	4.31	4.34
400.00	0.27	0.50	0.82	1.17	1.52	1.85	2.09	2.32	2.46	2.59	2.68	2.74	2.80	2.84	2.88	2.91	2.94	2.96	2.98	3.00	3.03	3.05	3.08	3.11	3.13	3.16	3.19	3.22	3.24
450.00	0.23	0.42	0.69	0.98	1.26	1.52	1.70	1.88	1.98	2.08	2.14	2.18	2.22	2.25	2.27	2.29	2.30	2.31	2.32	2.34	2.35	2.37	2.38	2.40	2.42	2.43	2.45	2.47	2.48
500.00	0.20	0.36	0.57	0.81	1.03	1.23	1.37	1.50	1.57	1.65	1.69	1.72	1.75	1.77	1.78	1.79	1.79	1.79	1.80	1.81	1.82	1.83	1.84	1.85	1.86	1.87	1.88	1.89	1.89
600.00	0.14	0.25	0.38	0.53	0.65	0.75	0.82	0.89	0.93	0.97	0.99	1.01	1.03	1.04	1.04	1.04	1.05	1.05	1.06	1.06	1.07	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.08
700.00	0.09	0.17	0.26	0.35	0.42	0.49	0.53	0.56	0.58	0.59	0.60	0.61	0.62	0.63	0.63	0.63	0.64	0.64	0.64	0.65	0.65	0.65	0.65	0.65	0.65	0.66	0.66	0.66	0.66
800.00	0.06	0.11	0.17	0.23	0.28	0.32	0.34	0.36	0.37	0.38	0.39	0.40	0.40	0.40	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42
900.00	0.04	0.08	0.11	0.15	0.18	0.21	0.22	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
1000.00	0.03	0.05	0.08	0.10	0.12	0.13	0.14	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
1100.00	0.02	0.04	0.05	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
1200.00	0.02	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
1300.00	0.01	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1400.00	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
1500.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03

Note: Contributions less than 0.01% can be ignored.

Fig. 22 ***Percentage penetration through a wall to areas above ground***

Percentage Penetration through a wall to areas above ground

$\sqrt{A}$ m =

Weight of Wall Material kg/m^2	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	35.00	40.00	45.00	50.00	60.00	70.00	80.00	90.00
0.00	22.25	19.08	17.62	15.74	14.48	13.32	12.25	11.34	10.71	10.11	9.55	9.07	8.72	8.39	8.07	7.21	6.44	5.79	5.31	4.55	3.99	3.49	3.05
50.00	18.64	16.52	14.64	13.03	11.94	10.93	10.01	9.23	8.69	8.17	7.69	7.25	6.86	6.50	6.15	5.55	5.05	4.55	4.19	3.89	3.12	2.69	2.32
100.00	15.59	13.76	12.15	10.77	9.82	8.96	8.17	7.50	7.03	6.60	6.19	5.79	5.40	5.04	4.70	4.29	3.96	3.58	3.30	2.82	2.44	2.07	1.76
150.00	12.73	11.19	9.83	8.67	7.85	7.11	6.45	5.89	5.54	5.21	4.89	4.60	4.33	4.07	3.84	3.44	3.10	2.78	2.52	2.13	1.84	1.59	1.36
200.00	10.39	9.08	7.94	6.96	6.27	5.65	5.09	4.64	4.36	4.10	3.86	3.64	3.46	3.28	3.11	2.75	2.42	2.15	1.92	1.61	1.39	1.23	1.05
250.00	8.38	7.29	6.34	5.54	5.00	4.51	4.07	3.70	3.45	3.22	3.00	2.81	2.66	2.51	2.38	2.10	1.86	1.68	1.50	1.25	1.10	0.96	0.84
300.00	6.76	5.85	5.06	4.40	3.98	3.59	3.25	2.95	2.73	2.53	2.34	2.18	2.06	1.94	1.83	1.61	1.43	1.30	1.17	0.97	0.86	0.75	0.67
350.00	5.41	4.66	4.02	3.48	3.16	2.86	2.59	2.36	2.19	2.03	1.88	1.75	1.64	1.54	1.45	1.28	1.13	1.01	0.91	0.77	0.67	0.58	0.51
400.00	4.33	3.72	3.19	2.76	2.51	2.28	2.07	1.89	1.75	1.62	1.50	1.39	1.31	1.23	1.15	1.01	0.89	0.79	0.71	0.60	0.52	0.45	0.39
450.00	3.42	2.95	2.53	2.20	2.00	1.82	1.66	1.51	1.39	1.28	1.18	1.09	1.02	0.96	0.90	0.78	0.69	0.62	0.56	0.47	0.41	0.35	0.31
500.00	2.72	2.35	2.02	1.76	1.60	1.45	1.32	1.21	1.11	1.01	0.93	0.86	0.80	0.75	0.70	0.62	0.54	0.48	0.44	0.37	0.33	0.28	0.24
600.00	1.77	1.53	1.33	1.16	1.04	0.93	0.84	0.76	0.70	0.64	0.59	0.55	0.51	0.48	0.45	0.39	0.34	0.31	0.28	0.24	0.20	0.17	0.15
700.00	1.14	1.00	0.87	0.76	0.69	0.62	0.57	0.51	0.47	0.44	0.40	0.37	0.34	0.32	0.30	0.25	0.22	0.19	0.17	0.15	0.12	0.11	0.09
800.00	0.76	0.66	0.58	0.50	0.45	0.41	0.36	0.33	0.30	0.28	0.25	0.23	0.22	0.20	0.19	0.16	0.14	0.13	0.11	0.09	0.08	0.07	0.06
900.00	0.50	0.43	0.37	0.32	0.29	0.26	0.23	0.21	0.19	0.18	0.16	0.15	0.14	0.13	0.12	0.11	0.09	0.08	0.08	0.06	0.06	0.05	0.04
1000.00	0.33	0.28	0.24	0.20	0.18	0.16	0.15	0.13	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03
1100.00	0.22	0.18	0.15	0.13	0.12	0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.02	0.02
1200.00	0.14	0.12	0.10	0.09	0.08	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
1300.00	0.09	0.08	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
1400.00	0.07	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
1500.00	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

NOTE: Contributions less than 0.01% can be ignored.

c. Calculate the weighted average for these contributions as (a) x (l-f) + (b) x (f) where f = fraction of apertures in that wall.

d. Corrected wall contribution becomes (c) x $\frac{4l}{P}$ = G%

ii. Contribution through an *internal wall* of a shelter room. Contributions are again calculated for each of the internal walls of the shelter room. The procedure is the same as for external walls except that apertures in the internal wall can be regarded as screened by material of the external wall partner. The calculation becomes as follows:

a. Calculate the wall contribution from Fig. 22 using $\sqrt{A}$ and the summed weights of the internal and external walls.

b. Calculate the wall contribution from Fig. 22 using $\sqrt{A}$ and the weight of the external wall material alone.

c. Calculate the weighted average for these contributions as (a) x (l-f) + (b) x (f) where f = fraction of apertures in that internal wall.

d. Corrected wall contribution becomes (c) x $\frac{4l}{P}$ = G%

The sum of the four wall contributions either as external or internal walls becomes the total wall contribution for the building = G_T%.

4. Correction for height above ground.

An allowance should be made for the height of the shelter room above ground level. This allowance is obtained by multiplying the total wall contribution G_T%, arrived at above, by a factor allowance taken from Fig. 23. For buildings on steeply sloping ground this correction factor will vary from wall to wall and the average height of the floor above the ground should be used for each wall.

Fig. 23 ***Correction for height above ground***

Floor height above ground (metres)	Reduction factor	Floor height above ground (metres)	Reduction factor
1.0	1.00	10.0	0.58
2.0	0.90	15.0	0.50
3.0	0.80	20.0	0.45
4.0	0.75	50.0	0.28
5.0	0.68		

5. Correction for shielding

A rough correction for shielding from other buildings may be applied as follows:

1. For buildings of at least the same size up to 10 metres away from the building considered the contribution through that wall is reduced to about one-half of the uncorrected value.

2. For buildings between 10 and 25 metres away from the wall being considered the contribution through that wall is reduced to three-quarters of the uncorrected value. This should apply only when the shielding wall is about one and a half times as long as the shielded wall. If this condition does not apply then the shielding effect should be ignored as should the effect of buildings more than 25 metres away.

3. If a shielding building is less than 1.5 metres away then the contribution through a shielded wall is reduced by about 80 per cent.

Fig. 24 ***Percentage penetration through a wall to areas below ground***

Percentage Penetration through a wall to areas below ground

$\sqrt{A}$ m

Weight of wall material kg/m²	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	35.00	40.00	45.00	50.00	60.00	70.00	80.00	90.00
0.00	0.55	0.65	0.89	1.09	1.25	1.36	1.43	1.49	1.48	1.44	1.41	1.40	1.39	1.38	1.37	1.27	1.19	1.11	1.04	0.91	0.81	0.70	0.61
50.00	0.55	0.65	0.89	1.09	1.25	1.36	1.43	1.49	1.48	1.44	1.41	1.40	1.39	1.38	1.37	1.27	1.19	1.11	1.04	0.91	0.81	0.70	0.61
100.00	0.55	0.65	0.88	1.08	1.24	1.35	1.43	1.48	1.47	1.43	1.40	1.39	1.38	1.37	1.36	1.27	1.19	1.11	1.04	0.91	0.81	0.69	0.61
150.00	0.48	0.57	0.76	0.93	1.07	1.18	1.24	1.29	1.29	1.27	1.25	1.23	1.21	1.19	1.17	1.10	1.03	0.97	0.90	0.79	0.71	0.61	0.54
200.00	0.42	0.49	0.66	0.80	0.93	1.03	1.08	1.12	1.12	1.12	1.11	1.08	1.06	1.04	1.01	0.95	0.90	0.84	0.78	0.69	0.62	0.53	0.47
250.00	0.34	0.41	0.55	0.67	0.78	0.86	0.91	0.94	0.95	0.95	0.95	0.92	0.90	0.88	0.86	0.80	0.75	0.70	0.66	0.58	0.52	0.45	0.39
300.00	0.28	0.33	0.46	0.56	0.65	0.71	0.76	0.79	0.80	0.80	0.80	0.78	0.76	0.74	0.72	0.68	0.63	0.61	0.56	0.49	0.43	0.37	0.33
350.00	0.23	0.27	0.37	0.46	0.53	0.59	0.63	0.65	0.67	0.67	0.67	0.66	0.64	0.62	0.61	0.57	0.53	0.51	0.46	0.41	0.36	0.31	0.27
400.00	0.19	0.22	0.30	0.38	0.44	0.48	0.52	0.54	0.55	0.56	0.56	0.55	0.53	0.52	0.51	0.48	0.44	0.43	0.39	0.34	0.30	0.26	0.22
450.00	0.16	0.18	0.25	0.32	0.37	0.40	0.43	0.45	0.45	0.46	0.46	0.45	0.43	0.42	0.42	0.39	0.36	0.35	0.32	0.28	0.24	0.21	0.19
500.00	0.13	0.15	0.21	0.26	0.30	0.33	0.35	0.37	0.37	0.37	0.37	0.36	0.35	0.35	0.34	0.32	0.30	0.30	0.26	0.23	0.20	0.17	0.15
600.00	0.09	0.10	0.14	0.17	0.20	0.22	0.23	0.24	0.24	0.24	0.24	0.23	0.23	0.22	0.22	0.21	0.19	0.19	0.17	0.15	0.13	0.12	0.10
700.00	0.06	0.07	0.09	0.11	0.13	0.14	0.15	0.15	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.12	0.12	0.11	0.10	0.09	0.08	0.07
800.00	0.04	0.05	0.06	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.07	0.06	0.05	0.05
900.00	0.03	0.03	0.04	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.03
1000.00	0.02	0.02	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02
1100.00	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
1200.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
1300.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1400.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1500.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

NOTE: Contributions less than 0.01% can be ignored.

2.3.3 Wall contributions (to basements)

Radiation from ground contamination entering an uncontaminated underground space which has neither roof nor surrounding walls above ground is all air scattered radiation. If there are surrounding walls above ground these will provide attenuation to the air scattered radiation which would, in their absence, enter the space. In addition, they also provide, to some slight extent, an additional scattering effect. If the space has an overhead cover at ground level or below this scattered radiation will be further attenuated by the material in the cover.

The scattered contribution from each wall to a room below ground is obtained from Fig. 24 using $\sqrt{A}$ and the weight of the wall material. This gives the contribution scattered through the wall considered to the midpoint of a basement room. The sum of contributions through all walls of the basement room gives the total contribution to the basement. This value is subject to multiplication by correction factors as follows:

i. For long and narrow buildings as calculated in 2.3.2(1.).

ii. For shielding from other buildings as calculated in 2.3.2(5.).

iii. For depth of basement, obtained directly from Fig. 25 using the depth of the basement floor below ground level and the floor area of the building in square metres.

iv. For the attenuation due to the basement ceiling obtained directly from Fig. 26 using the figure for the weight of the basement ceiling in kg/m^2.

The corrected value gives the total contribution to the basement = G_B%.

Wall contributions (to basements having walls partly above ground)

The procedure described above applies to basements which are entirely below ground level. However, if a basement wall is partly above ground level some additional radiation will enter through the exposed portion of the wall for which allowance must be made.

An approximate allowance can be made by calculating the contribution as if the wall were entirely exposed above ground level and multiplying this by the fraction of wall actually exposed. This result is then added to the contribution found by the procedure set out above.

PROTECTIVE FACTOR

Roof contribution	...R% =
Total of wall contributions	...G_T% =
Total	$(R + G_T\%)$ =
Protective factor	$\frac{100}{R + G_T}$ =

Fig. 25 ***Correction for depth of basement***

Area (m^2)	**Depth of basement** (metres)			
	4.5	6.00	9.00	12.00
9.0	0.4	0.2	0.05	0.01
45.0	0.6	0.3	0.1	0.05
250.0	0.8	0.6	0.4	0.2
950.0	0.8	0.7	0.6	0.4

Fig. 26 *Correction factor for attenuation by basement ceiling*

Weight of ceiling (kg/m^2)	Correction factor	Weight of ceiling (kg/m^2)	Correction factor
0	1.0	175	0.11
10	0.8	200	0.085
25	0.65	250	0.050
50	0.45	300	0.036
75	0.32	400	0.014
100	0.24	450	0.009
125	0.18	500	0.007
150	0.15		

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Miscellaneous Reports

GENERAL REFERENCES: Thermal Radiation from Nuclear Weapons

No.	Originator and Reference	Security Classification	Title
1	1957 Tripartite Conf. Paper No.24	Secret/Atomic	Thermal Radiation versus Time. Heat versus Distance. Dr. J.A. Carruthers, Canada.
2	Soviet Physics, J.E.T.P. Vo.34 (7) No.5, November, 1958, pp. 882-889	Unclassified	Radiation Cooling of Air. I. General Description of the Phenomena and the Weak Cooling Wave. Zel'dovich, Kompaneets and Raizer. Translation from J.E.T.P. (U.S.S.R.), Vol.34, pp.1278-1287, May, 1958.
3	Tri. Conf. on Weapons Effects 1957 Canadian Report 57/58	Secret/ZED	Thermal Radiation Versus Time

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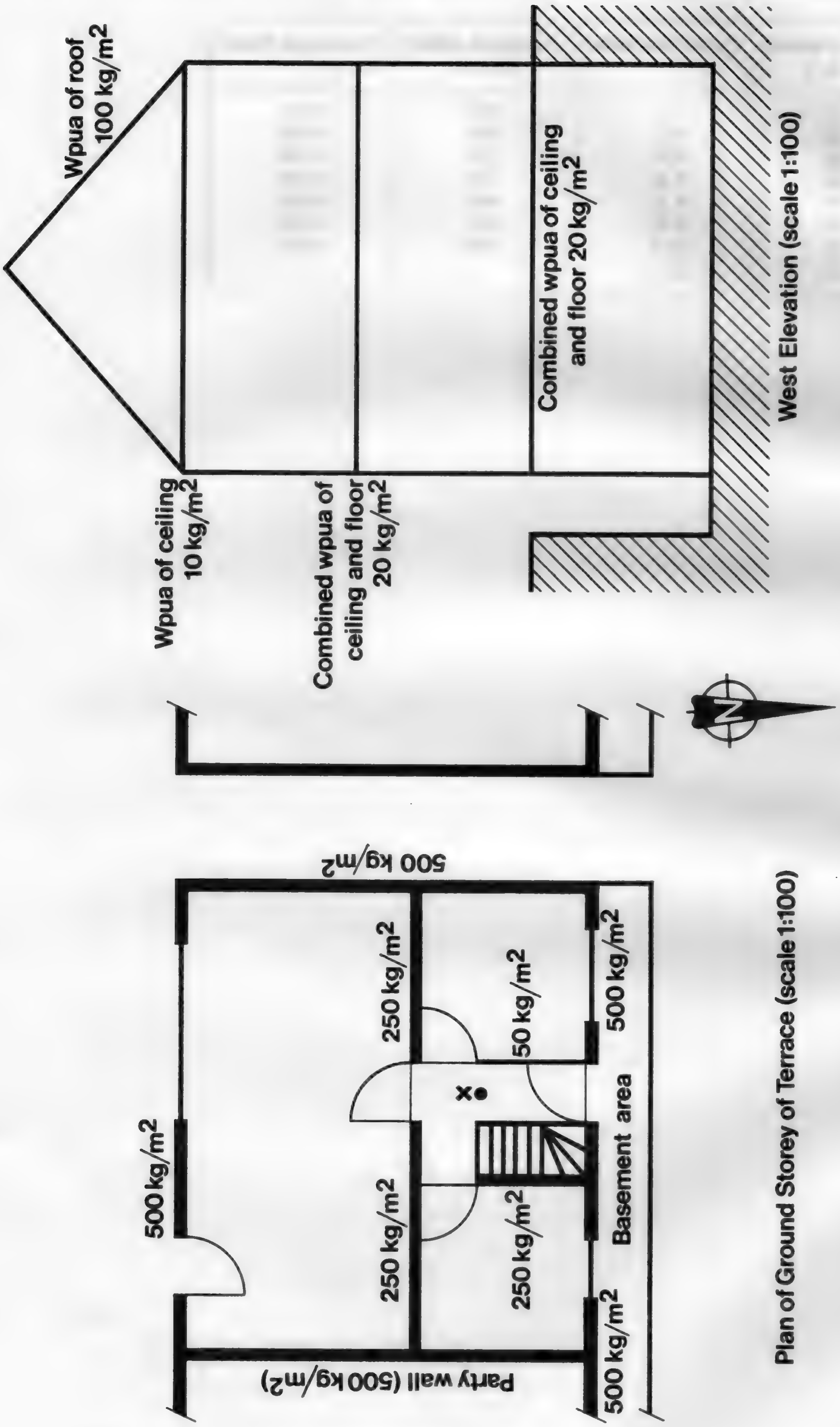
A.W.R.E. Report T37/57 1957 Tripartite Conference	Secret/Atomic	Operation Buffalo: Measurement of Ground Shock and Crater.

Originator and Reference	Security Classification	Title
A.F.S.W.P. Report I.T.R. 1404.	Official Use Only	Operation Plumbbob, Project 1.4. Ground Acceleration, Stress and Strain at High Incident Overpressures, 1957.
A.F.S.W.P. Report I.T.R.1427.	Official Use Only	Operation Plumbbob, Project 3.8. Soil Survey and Backfill Control in Frenchman Flat.
A.F.S.W.P. Report I.T.R. 1447	Official Use Only	Operation Plumbbob, 33.5. The Internal Environment of Underground Structures subjected to Nuclear Blast. I. The Occurrence of Dust.
A.F.S.W.P. Report I.T.R.1469	Official Use Only	Operation Plumbbob, Project 33.3. Tertiary Effects of Blast-Displacement.

A.F.S.W.P. Report 514 (Sanitized Edition) (M.O.D. Ref. 392)	Secret/Atomic	Cratering from Atomic Weapons. (ALO/US/39). Covers Bursts of all Sizes.
Civil Effects Test Group Preliminary Report ITR.1408 (M.O.D. Ref. No. 378)	Confidential/ Discreet	Operation Plumbbob, Project 1.8b. Effect of Rough Terrain on Drag Sensitive Targets.

Fig. 27 *Typical end-of-terrace house*



Examples of protective factor calculations

Typical two-storey end of terrace house

It is required to calculate the protective factor at point X on the ground floor and 0.3 m above floor level (Fig. 27).

Roof contribution

1. A_t area of roof	= 56 m^2
2. $\sqrt{A_t}$	= 7.5 m
3. H-x	= 7.2 m
4. $\frac{\sqrt{A_t}}{H\text{-}x}$	= 1.04
Weight of overhead material W_o	= 130 kg/m^2
Weight of internal partitions W_i	= 250 kg/m^2
$W_o + W_i$	= 380 kg/m^2

Since the South (S) and East (E) internal partition walls are of weights between 100 kg/m^2 and 300 kg/m^2 the modified calculation for roof contribution must be employed (see section 2.3.1 a–e).

5. A_r area of roof over refuge	= 15 m^2
6. $\sqrt{A_r}$	= 3.87 m
7. $\frac{\sqrt{A_r}}{H\text{-}x}$	= 0.54

From Fig. 18

i. $\frac{\sqrt{A_r}}{H\text{-}x}$ with W_o	= 0.53
ii. $\frac{\sqrt{A_t}}{H\text{-}x}$ with $W_o + W_i$	= 0.87
iii. $\frac{\sqrt{A_r}}{H\text{-}x}$ with $W_o + W_i$	= 0.28
Roof contribution R = i. + ii. – iii.	= 1.12%

Wall contributions

Area of floor = 56 m^2	$\sqrt{A}$ = 7.5
For N and S walls the length correction	$\frac{41}{P}$ = 1.06
E and W walls	$\frac{41}{P}$ = 0.94

East wall: since the E wall of the house is the heavy supporting party wall of the adjacent house the direct ground contribution in this direction is negligible. To this is added the part shielding by an internal wall of 250 kg/m^2. Therefore, the E wall contribution is regarded as zero.

West wall: the point X is partly shielded by both the E/W internal wall of 250 kg/m^2 and the N/S internal wall of 50 kg/m^2. The latter contribution is small enough to be discounted and the W wall contribution is calculated as follows:

From Fig. 22 using system 3i of calculation of wall contribution: (See 2.3.2)

The contribution through the wall at 50% for 500 kg/m^2 and 50% for 750 kg/m^2 using $\sqrt{A}$	= 1.22
Correction for shielding	= 0.5
Correction for length of wall	= 0.94
W wall contribution = 1.22 x 0.5 x 0.94	= 0.57%

South wall: the external S wall contains 30% apertures. The weight of this wall is averaged as 350 kg/m^2. Fraction of apertures in the internal wall is 0.125.

Weight of external wall W_e	= 350 kg/m^2
Weight of internal wall W_i	= 250 kg/m^2
$W_e + W_i$	= 600 kg/m^2

From Fig. 22 using system 3ii. of calculation of wall contribution, see 2.3.2.

a. Contribution using $W_e + W_i$ and $\sqrt{A}$ = 1.21

b. Contribution using W_e and $\sqrt{A}$ = 3.61

c. (a) x (1-f) + (b) x (f)
1.21 x 0.875 + 3.61 x 0.125 = 1.51
Correction for length of wall = 1.06
S wall contribution = 1.51 x 1.06 = 1.60

North wall: the internal wall east of the point X shields the aperture in the eastern end of the N wall. Therefore, the fraction of apertures in the N wall is taken as 0.5 for 62.5% of the total N wall. The remaining 37.5% of the N wall is taken as solid material at 500 kg/m^2.

From Fig. 22 using system 3i. for calculation of wall contribution: (See 2.3.2)

a. Contribution using W_e and $\sqrt{A}$ = 1.79

b. Contribution using 0 kg/m^2 and $\sqrt{A}$ = 16.14

c. (a) x (1-f) + (b) x (f)
1.79 x 0.5 + 16.14 x 0.5 = 8.96

Since this contribution is for 62.5% of the N wall the corrected contribution = 5.6%

Contribution for remaining 37.5% is calculated from
W_e and $\sqrt{A}$ x 0.375 = 0.67%
Total contribution 5.6% + 0.67% = 6.27%
Correction for length of wall = 1.06
N wall contribution 6.27 x 1.06 = 6.65%

PROTECTIVE FACTOR

Wall contributions G_T% = 8.82
Roof contributions R% = 1.12

$$PF = \frac{100}{R + G_T} = 10.06$$

PF = 10

Basement calculation

Contributions through the walls to the basement of the example building are obtained by following the format in 2.3.3. However, when calculating the contribution to the N wall in this particular example Fig. 22 is used, i.e. contribution through a wall to areas above ground, and a shielding factor of 0.2 is employed (about 80% reduction in transmission).

Improvement of protective factor

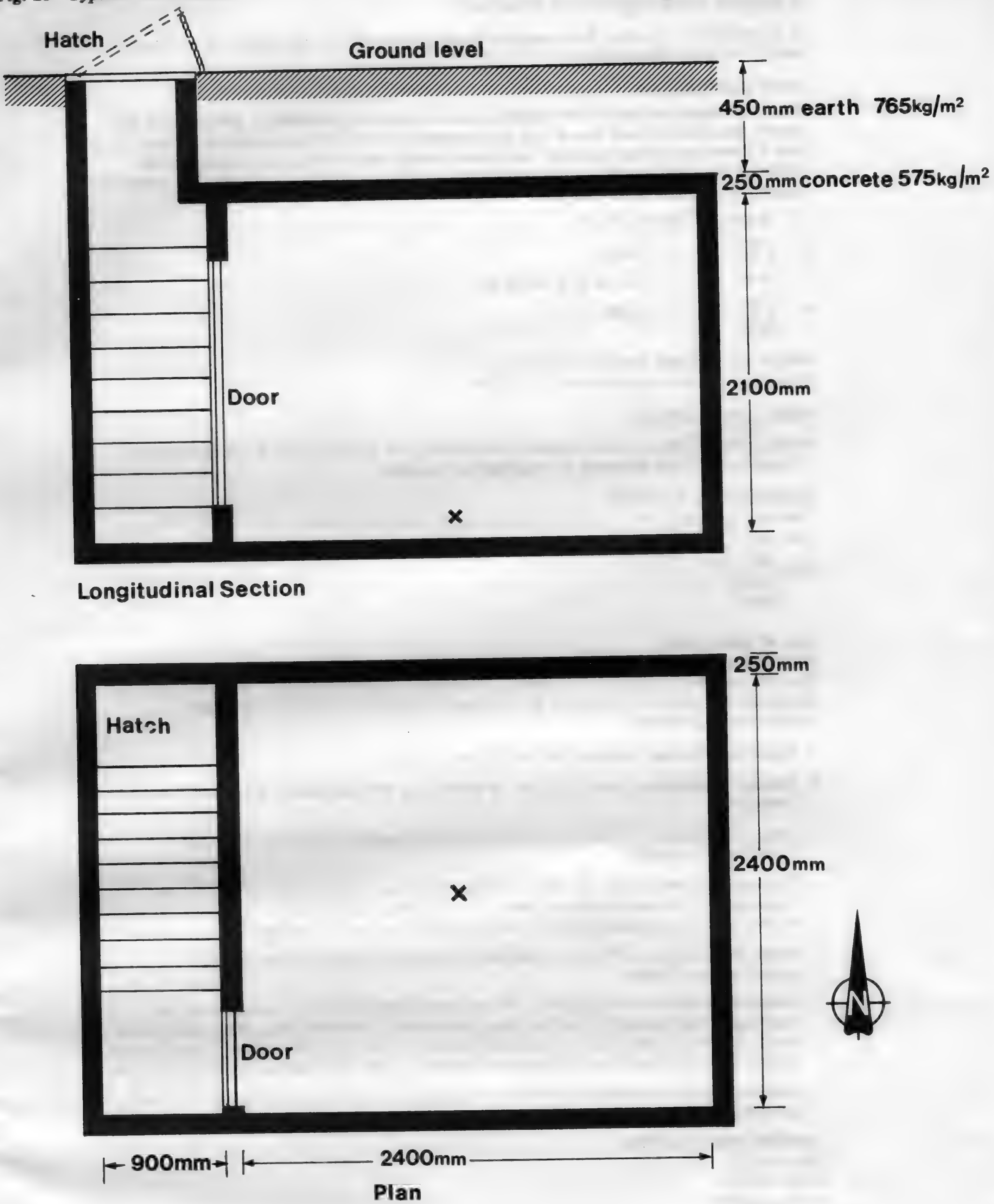
The PF of the example building can be substantially improved by blocking apertures in the external walls with material of the same density as the solid parts of those walls. The calculation then becomes:

E wall: unchanged = 0%
W wall: unchanged = 0.57%
S wall: all at 750 kg/m^2 = 0.69%
N wall: with 62.5% at 500 kg/m^2
37.5% at 750 kg/m^2 = 1.41%
Roof: unchanged = 1.12%
Wall contribution G_T% = 2.67
Roof contribution R% = 1.12
$R + G_T$ = 3.79

$$PF = \frac{100}{3.79}$$

PF = 26

Fig. 28 *Typical 'box' shelter*



Typical underground shelter

It is required to calculate the protective factor at a point X in the middle of the shelter and 0.3 m above floor level.

Roof contribution

Since the average weight of the internal partition wall of this shelter is greater than 300 kg/m^2 the effective roof area is that part contained within the square living portion of the box. Line-of-sight penetration for radiation through the hatchway to the door at the bottom of the well would be very small and would be negligible if the door and hatch are diagonally opposed across the well.

1. A_t area of roof = 5.76 m^2
2. $\sqrt{A_t}$ = 2.4 m
3. H-x = 2.5 m (2.8 m-0.3 m)
4. $\frac{\sqrt{A_t}}{H-x}$ = 0.96

Weight of overhead material = 1340 kg/m^2
From Fig. 21 roof contribution R = 0.025%

Wall contributions

Since the whole box is below ground surrounded by a density of earth the contribution through each of the walls can be regarded as negligible.

PROTECTIVE FACTOR
The only contribution of radiation which would reach the shelter is that passing through the roof

$$PF = \frac{100}{0.025} = 4000$$

Loss of hatch cover
Should the hatch cover be lost due to blast then some fallout could enter the well space. However, since the entrance is furnished by a flight of steps (probably concrete) then the distribution of fallout throughout the well space would be subject to a number of simplifying assumptions:

1. Hatchway has been taken as 900 x 1350 mm = 1.215 m^2.
2. Fallout is distributed over 1.215 m^2 of steps at an average height of about 1.5 m above floor level.
3. From Fig. 24 using $\sqrt{A}$ = 2.4 m and interior wall weight of 575 kg/m^2 gives contribution = 0.05%.

   The effective wall length for this contribution is only 1.35 m from a total 2.4 m consequently the contribution is reduced to 0.025%. This is further reduced to at least 0.01% due to a shielding factor from the outside wall of the shelter.
4. From Fig. 22 using $\sqrt{A}$ = 2.4 m and wall weight of 575 kg/m^2 gives a wall contribution of 0.8%.

   Again the effective wall length is 1.35 m from a total of 2.4 m, consequently the contribution is reduced to 0.45%. This contribution is further reduced by shielding to about 0.22% and then allowing that only 0.6 m of wall (of total height 2.1 m) is above fallout level this further reduction gives 0.063% as the final exposed wall contribution.
5. Addition of the two wall contributions calculated in 3 and 4 above gives overall wall contribution = 0.073%

PROTECTIVE FACTOR
R% = 0.025
G_T% = 0.073
R + G_T = 0.098

$$PF = \frac{100}{0.098} = 1020$$

Proforma for protective factor calculations

It is easier to use a standard proforma for tabulating data on building construction and the subsequent calculation of protective factors. A suitable style of proforma is given in this section.

Key to proforma

Roof contribution:

A_t = Total roof area (m^2)
A_r = Roof area within limits of refuge walls (m^2)
H-x = Distance from roof (m) to a point x (m) above floor
W_o = Weight of overhead material (kg/m^2)
W_w = Weight of interior wall material (kg/m^2)

Wall contribution:

A = Floor area of building (m^2)
P = Perimeter length of building (m)
W_e = Weight of exterior wall (kg/m^2)
l = Length of exterior wall (m)
W_i = Weight of interior wall(s) (kg/m^2)
f = Fraction of apertures in walls immediately adjoining refuge
h = Height above ground (m)
C_h = Height correction factor Fig. 23
d = Distance from exterior wall to wall of shielding building (m)
W_g = Weight of ground floor wall (kg/m^2)
W_c = Weight of basement ceiling (kg/m^2)
B = Depth of basement floor below ground (m)
C_B = Depth of correction factor Fig. 25

Contribution through roof

FORM 1

Data

A_t $\sqrt{A_t}$ =
A_r $\sqrt{A_r}$ =
H-x =
W_o =
W_w =
$W_o + W_w$ =

Case 1.

Interior wall weight less than 100 kg/m^2

(1) $\frac{\sqrt{A_t}}{H\text{-}x}$ =

(2) Fig. 21 using item 1 and W_o R% =

Case 2.

Interior wall weight greater than 300 kg/m^2

(1) $\frac{\sqrt{A_r}}{H\text{-}x}$ =

(2) Fig. 21 using item 1 and W_o R% =

Case 3.

Interior wall weight between 100 and 300 kg/m^2

(1) $\frac{\sqrt{A_t}}{H\text{-}x}$ =

(2) $\frac{\sqrt{A_r}}{H\text{-}x}$ =

(3) Fig. 21 using item 2 and W_o =
(4) Fig. 21 using item 1 and $W_o + W_w$ =
(5) Fig. 21 using item 2 and $W_o + W_w$ =
(6) (Item 3) + (Item 4) – (Item 5) R% =

Contribution through wall

FORM 2

(Areas above ground)

Data $A =$ $\sqrt{A} =$

$P =$

		N	E	S	W
	$W_e =$				
	$l =$				
	$W_i =$				
	$f =$				
	$h =$				
	$C_h =$				
	$d =$				
	$\frac{4l}{P} =$				
	$W_e + W_i =$				
Exterior walls of shelter	(1) Fig. 22 and W_e* =				
	(2) Fig. 22 and 0 kg/m^2 =				
	(3) (Item 1) x (l-f) + (Item 2) x f =				
	(4) Wall contribution Item 3 x $\frac{4l}{P}$ x C_h =				
Interior walls of shelter	(1) Fig. 22 and W_e* + W_i* =				
	(2) Fig. 22 and W_e* =				
	(3) (Item 1) x (l-f) + (Item 2) x f =				
	(4) Wall contribution Item 3 x $\frac{4l}{P}$ x C_h =				

***Shielding factor:**

shielding building (a) 1.5 m — contribution reduced by 80%

(b) 1.5 – 10 m — contribution reduced by 50%

(c) 10 – 25 m — contribution reduced by 25%

(see main copy for exceptions)

Contribution through walls

FORM 3

(Into basements)

Data $A =$ $\sqrt{A} =$

$P =$

	N	E	S	W
$W_g =$				
$l =$				
$W_c =$				
$B =$				
$C_B =$				
(1) Fig. 24 and W_g =				
(2) Fig. 26 and W_c attenuation =				
(3) Uncorrected ground contribution Item 1 x Item 2 =				
(4) Corrected wall contribution Item 3 x $\frac{4l}{P}$ x C_B =				

Protective factor

Roof contribution $R\% =$

Wall contributions $G_T\% =$

$R + G_T =$

$$PF = \frac{100}{R + G_T}$$

A.F.S.W.P. Report ITR-1450	Official Use Only	Operation Plumbbob, Project 30.3. Evaluation of F.C.D.A. Family Shelter Mark 1 for Protection against Nuclear Weapons.
A.F.S.W.P. Report WT-1218	Official Use Only	Operation Teapot, Project 34.1 and 34.3. Evaluation of Various Types of Personnel Shelters Exposed to an Atomic Explosion.

Chapter 3

A.W.R.E. Report T47/57	Confidential	The Effect of Earth Covers on the Resistance of Shelter Roofs.
A.M. Report AWEC/P(57)35	Secret/Atomic	The Vulnerability of Airfield Runways to Nuclear Explosions. Henderson.

Structural design of domestic nuclear shelters

General approach to structural design for blast resistance 3.1

In addition to providing protection against thermal and nuclear radiation, purpose-built nuclear shelters should be designed to resist the air blast effects of nuclear explosions.

Shelters are usually placed below ground so that the effects of blast are reduced, although comparable levels of blast (and fallout) protection can be obtained above ground by using thicker elements. Where structural elements are required to sustain relatively large direct blast loads they need to be of heavy ductile construction e.g. reinforced concrete. However, structures constructed of thin-walled materials such as glass reinforced plastic (GRP) or thin metal sheeting can also be used in shelters, but their ability to withstand blast loading depends on their shape, how carefully they have been manufactured and their interaction with the earth cover. Spheres or similar shapes are the most effective but special attention must be given to weak points such as joints and entrances. Thin walled lightweight structural shells obviously offer little protection against radiation, and need to be combined with dense cover to obtain radiation protection.

The effects of blast loading are reduced significantly when shelters are deeply buried (i.e. when the earth cover is equal to or greater than about half the width of the shelter) as the overpressure is attenuated with depth and the soil acts as an arch above the shelter and takes part of the vertical load.

This chapter sets out guidelines for the structural design of surface or shallow buried rectangular domestic shelters constructed of reinforced concrete, or steel plate for overpressures up to 3 atmospheres (315 kPa or 45 psi), and provides a simplified dynamic design method. Above this overpressure other factors will need to be taken into consideration. Lightweight flexible building material such as GRP or thin metal sheets etc. and the design of deeply buried shelters are not covered in this book as further work and research has to be carried out before simple design rules can be given. Design guidance will be published in due course on these aspects of shelter design.

The design rules in this chapter have been limited to the analysis of one- and two-way spanning slabs likely to be used in rectangular shelters as this shape is considered to be the most cost effective for materials such as reinforced concrete. The general principles of dynamic analysis covered can be used for shelters of other shapes e.g. cylinders, arches, spheres etc. The method of analysis presented is not mandatory and the design engineer can use other appropriate methods.

It is recommended that the structural design and construction of shelters, designed for blast loading, should be supervised by a chartered structural or civil engineer experienced in structural design and practice.

Simplified dynamic blast design 3.2

Basic principles of blast-resistant design of ductile structural elements 3.2.1

The ultimate load capacity of a ductile structural element subjected to blast loading can be determined by considering its capability of sustaining external load by relatively large plastic deformations. The design rules in this guide will limit the magnitude of the plastic deformations and thus the level of damage to the structural elements to a condition of moderate damage, where there will be considerable yielding of steel and cracking of concrete, but no significant impairment of the resistance to further loading.

3.2.2 Blast loads

Blast load F on surface and shallow buried shelters are presented in Fig. 29.

Fig. 29 ***Blast loads on shallow buried and surface shelters***

	Shallow buried		Surface
	In dry ground	High water level	
Roof + floors	P_{so}	P_{so}	P_{so}
Walls	$0.5\ P_{so}$	P_{so}	$2.3\ P_{so}$

P_{so} = overpressure

Dead loads, soil and water loads should be added to the blast loads given above.

1. Roof elements

The roof should be designed for the full overpressure, plus the dead loads of the concrete and earth cover.

2. Wall elements

Surface shelters require thicker walls than buried structures, as the blast wave is reflected and increased when it comes into contact with the face of the shelters. A value of 2.3 times the overpressure should be used for design.

Walls of shallow buried shelters are subjected to smaller loads than the above-ground case. For the purpose of these design notes a value of one-half the overpressure should be used, unless the shelter is constructed in ground with a high water table, where the full overpressure should be used. The earth and water pressure acting on the walls must also be added to the blast loading.

3. Floor slabs

The floor slab should be designed for blast loading and the dead weight of the shelter. The design blast loading acting on the floor should be taken as that acting on the roof, the dead weight of the entire shelter (with the exception of the floor slab) and any earth cover are to be included as permanent loads.

An approximate conservative analysis can be carried out assuming that these loads are uniformly distributed over the floor. In reality there will be a decrease in the calculated maximum bending moment as a result of the arching effect of the soil, but this will depend on the type of soil and position of the ground water level.

3.2.3 Dynamic analysis of shelter elements

A rigorous dynamic design of a shelter will depend on the mass and stiffness of the shelter elements, and if a full dynamic design is considered applicable, the design engineer should refer to the many publications on dynamic design.

For ductile thick walled structures exposed to overpressure of up to 3 atmospheres from nuclear explosions, a safe solution can be obtained by assuming that the load duration is relatively long in relation to the period of inelastic response of the elements, and the following equation can be used:

$$r_u = F\left(\frac{1}{1-\frac{1}{2\mu}}\right)$$

where required r_u = ultimate unit resistance

F = blast load (from Fig. 26)

μ = ductility ratio $= \dfrac{\text{permitted deflection}}{\text{deflection at the elastic limit}}$

The amount of plastic deformation can be controlled by varying the value of μ. Below $\mu = 1$ the element will remain elastic and above $\mu = 1$ plastic deformation will take place. For moderate damage μ should be taken as 3 and the equation becomes:

$$r_u = 1.2\ F$$

The expression $\frac{1}{1 - \frac{1}{2\mu}}$ can be considered in terms of a partial safety factor for load γ_f.

Thus for moderate damage $\gamma_f = 1.2$.

Design of rectangular reinforced concrete slabs for blast loading 3.2.4

Allowable stresses *3.2.4.1*

The behaviour of structural elements subjected to blast loading depends on the ultimate strength and the ductility of its material. Reinforced concrete has sufficient ductility to allow dynamic increase factors (DIF) to be applied to the characteristic strengths of materials.

Dynamic increase factors for reinforced concrete are given in Fig. 30.

Fig. 30 ***Dynamic increase factors (DIF)***

Stresses	DIF
Steel – bending	1.10
Concrete – compression	1.25

Ultimate unit resistance *3.2.4.2*

The ultimate resistance of an element varies as:

a. The distribution of applied loads.
b. The geometry of the element.
c. The percentage of reinforcement.
d. Type of support.

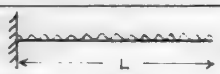
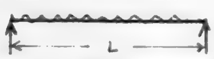
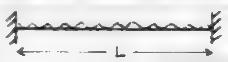
One-way elements

For one-way elements the ultimate resistance is a function of the moment capacity at the first yield plus the moment capacity due to subsequent yielding at other critical sections.

Values of ultimate unit resistance r_u for several one-way elements are shown in Fig. 31 where the following symbols are used:

M_N = ultimate unit negative moment capacity at the support.
M_p = ultimate unit positive moment capacity at mid-span.
L = span length.

Fig. 31 ***Ultimate resistance of one-way elements***

Edge condition		**Ultimate unit resistance r_u**
Cantilever		$\frac{2\ M_N}{L^2}$
Simple supports		$\frac{8\ M_p}{L^2}$
Fixed supports		$\frac{8}{L^2}(M_N + M_p)$
Fixed simple support		$\frac{4}{L^2}(M_N + 2\ M_p)$

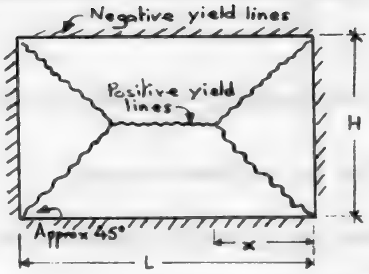
Two-way elements

Two-way elements can be analysed using the yield line theory.

The value of the ultimate unit resistance r_u for a two-way slab is given:

$$r_u = \frac{8\ (M_N + M_P)\ (3\ L-x)}{H^2\ (3\ L-4x)} \text{short span}$$

$$r_u = \frac{5\ (M_N + M_P)}{x^2} \text{ long span}$$



3.2.4.3 *Ultimate unit moment capacity*

The ultimate unit moment capacity of a reinforced concrete element subjected to blast loading can be found by using the equations given in Cl 3.3.5.3 of CP 110, but with modified partial safety factors for steel and concrete, $\gamma_m = 1$.

Thus equation (1) in CP 110 becomes:

$$M_u = f_{y_{dynamic}}\ A_s\ Z$$

Equation (2) in CP 110 becomes:

$$M_u = 0.225\ f_{cu_{dynamic}}\ bd^2$$

and equation (5) in CP 110 becomes:

$$z = (1 - \frac{0.84\ f_{y_{dynamic}}\ A_s}{f_{cu}\ bd})\ d \text{ but not greater than .95d}$$

where

M_u = ultimate resistance moment

$f_{y_{dynamic}}$ = (characteristic strength of reinforcement) x (a dynamic increase factor) from Fig. 30

$f_{cu_{dynamic}}$ = (characteristic strength of concrete) x (a dynamic increase factor) from Fig. 30

z = lever arm

A_s = area tensile reinforcement

b = width of section

d = effective depth of section.

The ultimate resistance of the section may be taken as the lesser of the values obtained from the modified CP 110 equations 1 and 2.

3.2.4.4 *Ultimate shear capacity*

Slabs and walls should be designed without shear reinforcement.

The ultimate shear stress in reinforced concrete should be limited to 0.04 f_{cu} where f_{cu} = characteristic strength of concrete.

The ultimate shear stresses on one-way spanning elements are given in Fig. 32.

Fig. 32 ***Ultimate shear on one-way spanning elements***

Edge conditions	Ultimate shear stress on a section
Cantilever	$r_u \frac{(L-d)}{d}$
Fixed or pinned support	$r_u \frac{(L/2-d)}{d}$

where d = effective depth of section.

Minimum area of flexural reinforcement 3.2.4.5

To ensure the proper structural behaviour and also to prevent excessive cracking or deformations, the minimum areas of flexural reinforcement given in Fig. 33 are recommended:

Fig. 33 ***Minimum area of flexural reinforcement***

Reinforcement	Mild steel	Hot rolled high tensile bars
Main	0.25% bd	0.20% bd
Secondary	0.15% bd	0.12% bd

where d = effective depth of slab required to resist blast loading.

Design of steel plate elements 3.2.5

A limit state British Standard Code of Practice is under preparation for structural steelwork. In the meantime the Constrado publication *Plastic Design* can be used as a guide.

Allowable stresses 3.2.5.1

A dynamic increase factor of 1.10 can be used for bending of steel.

Ultimate unit resistance 3.2.5.2

The ultimate unit resistance of steel plate elements can also be determined from the yield line theory and thus the table and equations in 3.2.4.2 can be used.

Plastic moment of resistance 3.2.5.3

The greatest moment a steel member can sustain at full plasticity is the plastic moment of resistance:

$$M_u = Z_p \times f_{y_{dynamic}}$$

where

Z_p = plastic modulus $= \frac{bd^2}{4}$ for a rectangular section, and

$f_{y_{dynamic}}$ = (yield stress of steel) x (a dynamic increase factor)

Shear 3.2.5.4

The dynamic shear stress for mild steel should not exceed 172 N/mm^2.

Connections 3.2.5.5

Bolts should be black bolts to BS 4190. High strength friction grip bolts should not be used.

The allowable dynamic stresses for bolts and welds are as follows:

Bolts: Tension 275 N/mm^2
Shear 170 N/mm^2
Bearing 410 N/mm^2

Welds: Tension or compression 275 N/mm^2
Shear 170 N/mm^2

3.2.6 Notes on construction

1. Materials and construction standards for reinforced concrete should generally comply with the British Standard Code of Practice CP 110 and BS 449 for structural steelwork.
2. Reinforcement is to be mild steel or hot rolled high tensile bars to BS 4449. Cold worked high yield bars must not be used.
3. Continuous reinforcement should be used wherever possible. Where it is necessary to have reinforcement laps the lap length must = 72 x diameter of bar.
4. All concrete must be thoroughly vibrated.
5. Construction joints should be kept to a minimum.
6. A 225 mm wall kicker should be cast with the floor slab.
7. No material should be applied to the inside walls or ceiling of the shelter that could become a hazard.
8. Sulphate resisting cement should be used in circumstances where soils contain sulphates to a dangerous degree. No other additives should be added to concrete.
9. A sump should be provided at the lowest level to enable any water that enters the shelter to be collected.
10. External elements of buried and shallow buried shelters should be protected by a waterproof membrane.

3.2.7 Suggested reinforced concrete detailing

Suggested reinforced concrete detailing is shown in Figs. 34 and 35.

3.2.8 Design procedure

Step 1. Determine design stresses using dynamic increase factors from Fig. 30.

Step 2. Determine external blast load for the element under consideration from Fig. 29.

Step 3. Calculate the ultimate resistance r_u required to sustain the design overpressure.

For moderate damage $\gamma_f = 1.2$

$$\therefore r_u = 1.2\,F$$

where F = blast load from Fig. 29.

Add the dead and earth pressure loads to obtain the required r_u.

Step 4. Calculate the magnitude of the ultimate moment capacity required to accommodate the required r_u.

Step 5. Select a depth of member and a percentage of reinforcement to provide an adequate ultimate moment capacity.

Step 6. Check that the percentage of reinforcement provided exceeds the minimum values given in Fig. 33.

Step 7. Check shear.

Step 8. Check the radiation protective factor in accordance with Chapter 2.

Examples of the simplified method of design are given on pages 53, 54 and 55.

Example 1. One atmosphere shallow buried domestic shelter. Reinforced concrete roof.

Data	Calculation	Results
	Given: 2440 mm clear span, one way spanning with fixed supports. 250 mm thick slab, with 50 mm cover to steel.	
CP110 Table 2 and 3	Grade 30 concrete $f_{cu} = 30\ N/mm^2$ Mild steel $f_y = 250\ N/mm^2$ Consider 1 mm width of slab.	$f_{cu} =$ $30\ N/mm^2$ $f_y =$ $250\ N/mm^2$
DIFs from Fig. 30	**Step 1: Design stresses** $f_{cu_{dynamic}} = 1.25 \times 30 = 37.5\ N/mm^2$ $f_{y_{dynamic}} = 1.1 \times 250 = 275\ N/mm^2$	$f_{cu_{dynamic}} =$ $37.5\ N/mm^2$ $f_{cu_{dynamic}} =$ $275\ N/mm^2$
Fig. 29	**Step 2: Blast load** $F = P_{so} = 1$ atmos $= 0.1\ N/mm^2$ (14.5 psi)	$F =$ $0.1\ N/mm^2$ (14.5 psi)
For $\mu = 3$	**Step 3: Required r_u.** r_u for blast $= 1.2F = 1.2 \times 0.1 = .12\ N/mm^2$ Add dead load conc + soil $= \underline{.014}$ $= 0.134\ N/mm^2$	Req'd $r_u =$ $0.134\ N/mm^2$ (19.48 psi)
Fig. 31 Provide same steel top and bottom	**Step 4: Required M_u.** A fixed one-way spanning slab M_u req'd $= \dfrac{r_u L^2}{16}$ $= \dfrac{.134 \times 2440^2}{16} = 49861$ Nmm/mm	M_u req'd $=$ 49861 Nmm/mm run
250 mm slab $A_s =$ $1.005\ mm^2/mm$ run $d = 250 - 58$ $= 192$	**Step 5: Reinforcement** Try R16 @ 200 c/c $z = (1 - \dfrac{0.84\ f_{y_{dynamic}}\ A_s)}{f_{cu}\ bd}\ d$ $= 192 - \dfrac{0.84 \times 275 \times 1.005}{37.5} = 185.8$ or $= .95 \times 192 = 182$ mm Take $z = 182$ mm $\therefore M_u = f_{y_{dynamic}}\ A_s\ z$ $= 275 \times 1.005 \times 182 = 50{,}300$ Nmm/mm run >49861 Nmm/mm run	$z = 182$ mm Use R16 @ 200 c/c top and bottom in short span
Fig. 33	**Step 6: Check min steel** Main $= .25\% \times 1 \times 192 = .48\ mm^2/mm$ $1.005\ mm^2/mm$ provided OK. Other $0.15\% \times 1 \times 192 = .29\ mm^2/mm$ Provide R10 @ 200 c/c ($0.392\ mm^2/mm$)	Use R10 @ 200 c/c top and bottom sec steel

Allowable shear $= 0.04\ f_{cu}$ $= 0.04 \times 30$ $= 1.2\ N/mm^2$	**Step 7: Check shear** Shear $= \dfrac{r_u \left(\frac{L}{2} - d\right)}{d} = \dfrac{.134\ (1220 - 192)}{192} = 0.72\ N/mm^2$ $< 1.2\ N/mm^2$ OK	
	Summary of results Slab thickness : 250 mm Main steel : R16 @ 200 c/c top and bottom Sec steel : R10 @ 200 c/c top and bottom	

R.A.E. Memo. G.W/59230/FIR.	Secret/Discreet	Nuclear Weapon Effects on Ballistic Missile Re-entry Heads.
A.W.R.E. Report T8/58	Confidential	Operation Antler. Target Response Group Effects on Swift Aircraft.

U.S.A.F. Cambridge Res. Centre. Air Force Surveys in Geophysics No. 27	Secret	Lethal Gust and Overpressure Envelopes for the TU-4. Haskell.

U.K. Reports — DAMAGE TO AIRCRAFT: Thermal Radiation

No.	Originator and Reference	Security Classification	Title
1	Min. of Defence Tripartite Conference February, 1954. Section No. 4.	Secret/ U.K. Eyes Only	Thermal and Blast Effects on Aircraft
2	A.W.R.E. Report No.T28/58	Confidential	Operation Buffalo. Target Response Tests. Materials Group. Part 9C. Effects on Aircraft Wind Screens.

U.S. Reports — DAMAGE TO AIRCRAFT: Nuclear Radiation, Contamination and Decontamination

No.	Originator and Reference	Security Classification	Title
1	U.S.Naval Radiological Defence Laboratory. Report U.S.N./R.D.L.-362. August 1952. (M.O.D.Ref. No. 267) (T.I.L. Ref. P.60499) ACSIL 5613913.	Confidential/ Discreet	Radiological Factors Affecting the Operation of Aircraft in Atomic Warfare. Progress Report prepared for the Bureau of Aeronautics, Part A. For Part B (Secret) see DRB 54/15494.

U.K. Reports — DAMAGE TO AIRCRAFT: Nuclear Radiation, Contamination and Decontamination

No.	Originator and Reference	Security Classification	Title
1	Air Ministry Sc. 2 Memo. 254	Top Secret Atomic U.K.E.O.	The Danger to Bombers from Radio-Active Clouds over a Realistic Target Area.
2	A.W.R.E. T106/54	Secret	The Prevention and Removal of Radioactive Contamination, Part VI. Decontamination of Aircraft, and Health Control at Woomera and Amberley.

A.F.S.W.P. (Availability in U.K. unknown)	(Secret/ Discreet)	Operation Plumbbob, Project 6.2. Near Field Measurements of the Electro-Magnetic Effect. Report by Diamond Ordnance Fuse Labs. Project 6.5. Effects of Nuclear Radiation on NIKE. B.G.M. Components, Materials and Systems. Report by White Sands Proving Ground.
A.F.S.W.P. (Availability in U.K. Unknown)	(Secret/ Discreet)	Operation Hardtack. Radiation Effects on Electronic Fuse Components. Report by Diamond Ordnance Fuse Labs. (Covers Nuclear and Electro-magnetic effects on Active Missile Fuse Systems before, during and after Nuclear Detonations.)

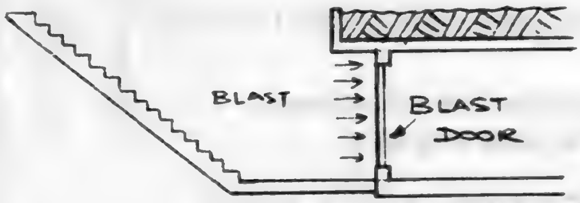
A.F.S.W.P. Report WT-1222	Official Use only	Operation Teapot: Project 32. Exposure of Foods and Food Stuffs to Nuclear Explosions (A Summary of Results).

A.F.S.W.P. Report ITR-1408 6th December, 1957, (M.O.D. Ref.No.378).	Confidential/ Discreet	Operation Plumbbob, Project 1.8b, Preliminary Report, Effects of Rough Terrain on Drag-Sensitive Targets.

Originator and Reference	Security Classification	Title
A.W.R.E. E3/55	Secret/Discreet	Total Residual Gamma Dose from Randomly Distributed Ground Bursts of 5 megaton Thermonuclear Weapons.
A.W.R.E. Report T.50/57	Secret/Atomic	The Remote Measurement of the Variation with Time of Gamma Dose Rate from Fallout. Jones.
Nature, Vol.177 No.4517 p.990	Unclassified	Relationship between Air Concentration of Radioactive Fission Products and Fallout Following Operation Teapot. Blifford et al. U.S.N.R.L.

Home Office CD/SA No. 69, January, 1956	Unclassified	The Penetration of Gamma Radiation from a Uniform Contamination into Houses. McDonald.
A.W.R.E. Report O-35/36 (X)	Official Use Only	Dose Rates from Ground Contaminated with Residual Radioactive Material from an Atomic Explosion.
A.W.R.E. Report E-6/56	Secret/Atomic U.K. Eyes Only	The Dispersion of Radioactivity in the Sea after the Explosion of an Atomic Weapon (Operations Crossroads and Hurricane).
A.W.R.E. Report T-60/57	Secret	Operation Buffalo. Radioactivity Rates and Beta/Gamma Ratios in Atomic Bomb Clouds.

Example 2. One atmosphere shallow buried domestic shelter. Steel blast door.

	Calculation	Results
	Given: Clear opening 600 mm x 1800 mm Mild steel f_y = 250 N/mm^2 	f_y = 250
DIF's from Fig. 30	**Step 1: Design stresses** $f_{y_{dynamic}} = 1.1 \times 250 = 275$ N/mm^2	$f_{y_{dynamic}}$ = 275 N/mm^2
Fig. 29	**Step 2: Blast load** $F = 2.3\ P_{so} = 2.3 \times 0.1 = 0.23$ N/mm^2 (33.35 psi)	F = 0.23 N/mm^2 (33.35 psi)
For $\mu = 3$	**Step 3: Required r_u** r_u for blast = 1.2F = 1.2 x .23 = 0.276 N/mm^2	Req'd r_u = .276 N/mm^2 (40 psi)
	Step 4: Required M_u Eff span = 650 Slab one way spanning, simply supported M_u req'd $= \frac{.276 \times 620^2}{8} = 13262$ Nmm/mm run	M_u req'd = 13262 Nmm/mm run
Try 15 mm plate	**Member size** (Consider 1 mm width) $Zp = \frac{bd^2}{4} = 1 \times \frac{15^2}{4} = 56.26$ mm^2 M_u provided = $Zp \times f_y$ = 56.25 x 275 = 15468 Nmm/mm run > 13262 Nmm/mm run OK	Use 15 mm mild steel plate

Note

Thickness of blast door may have to be increased for fallout protection against radiation, e.g. by steel/conc sandwich construction.

Fig. 34 *Reinforced concrete simply supported elements*

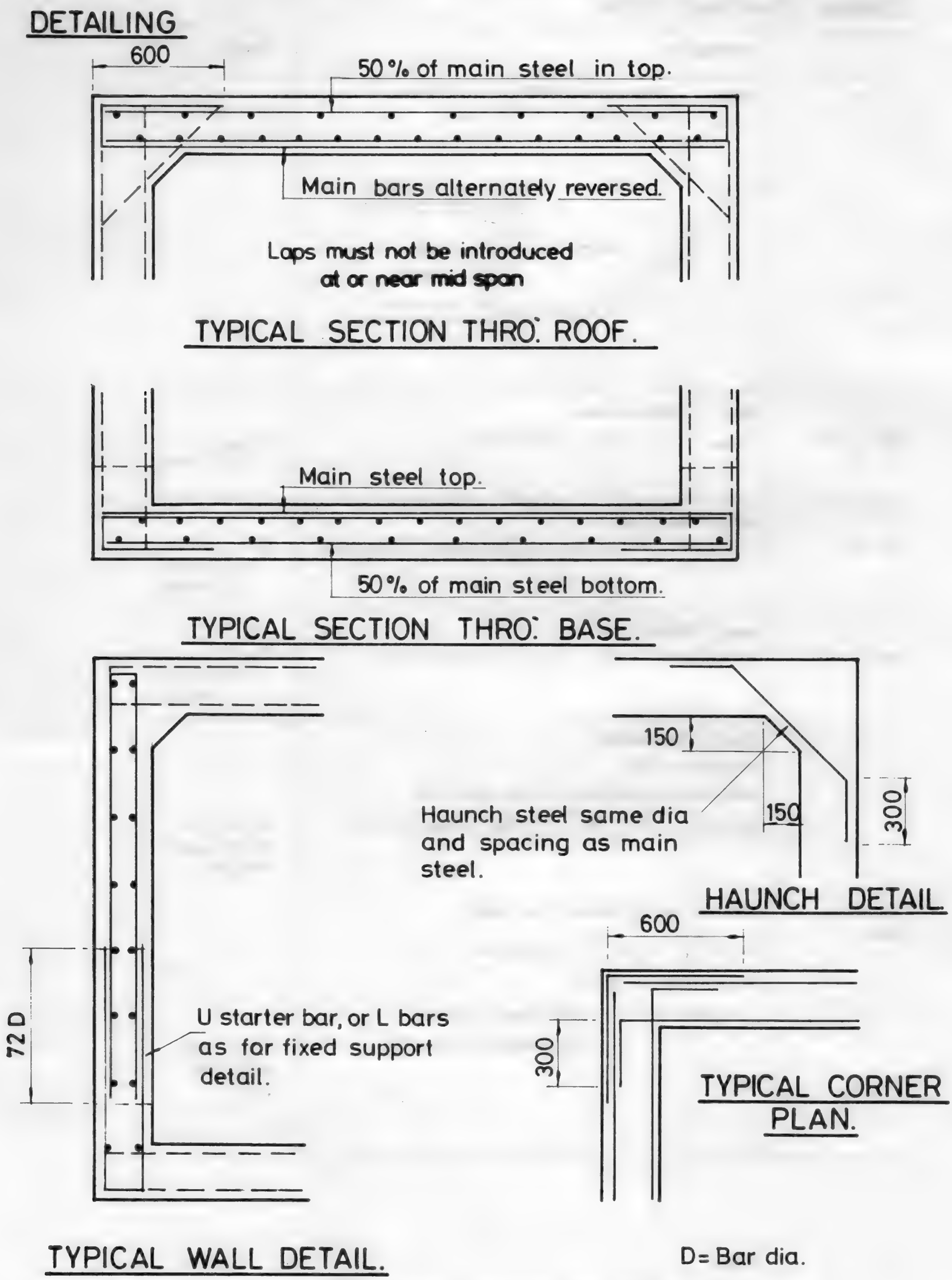
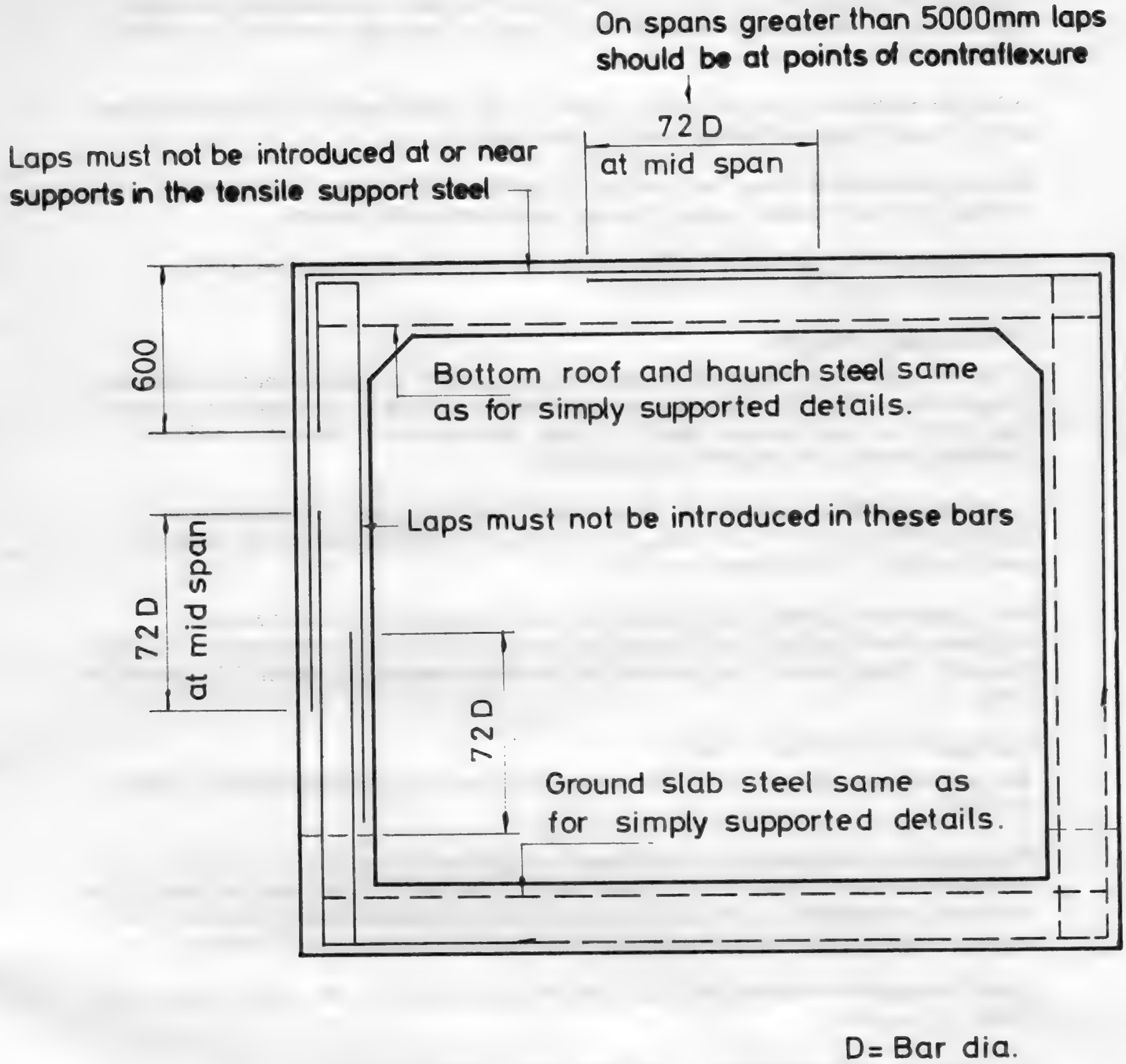


Fig. 35 *Reinforced concrete fixed supports*



3.3 Design analysis and computer study

3.3.1 Introduction

A computer analysis can be used to examine in detail a preliminary hand-worked design. The hand analysis will have established section sizes and preliminary reinforcement details.

The computer would then be used to derive moments, shears and deflections at points over the whole structure for combinations of dead load and static live load due to blast overpressure.

A further analysis is then used to give factors for the amplification of the results because of the dynamic nature of a blast pressure wave loading.

Having established moments and shears at all points under the static and dynamic loading, the reinforcement can be efficiently and economically detailed.

An example of this method of design is set out in the following pages, and on the attached drawings, Figs. 36–43 inclusive.

3.3.2 Preliminary design

If the structure is to be analysed in detail using a computer program then the preliminary design need only establish section sizes, which will be verified by the computer analysis, and preliminary reinforcement details, to assess the efficiency of the section and the feasibility of fixing the required steel quantities.

A full hand analysis procedure for blast-resistant design is given in ***Introduction to Structural Dynamics*** by J. M. Biggs, but even this method does not give the detailed results possible with a computer analysis.

For a preliminary design a yield line analysis of a top slab and side wall would be sufficient. Each member should be analysed as a built-in two-way spanning slab. A load factor of 1.2 and dynamic increase strength factors as described in section 3.3.6 should be used.

3.3.3 Computer analysis - static

The general arrangement of the structure derived from the preliminary analysis is shown on Fig. 38.

The structure is modelled as a three-dimensional grillage and analysed on the CCS Computer program LEAP. In this type of analysis the solid slab and wall members of the structure are modelled as a net of rod members with equivalent section properties. The model for this structure is shown on Fig. 39. It has 473 members and 118 nodes.

Loads are applied to each of the 'rod' members in proportion to the area of slab or wall which they represent.

The following individual loads are calculated and applied separately:

(a) Structural dead weight, using the dimensions and section thicknesses established in the preliminary design.
(b) Surcharge due to the weight of soil and paving laid on top of the shelter.
(c) Soil pressures due to the backfill around the structure. For this exercise it was assumed that the backfill is granular with a density of 2 tonnes/m^3 and an angle of internal friction of 25°.
(d) The effect of buoyancy on the structure caused by water reaching ground level.
(e) An overpressure, applied as a static load, due to the peak value of the blast wave from a nuclear explosion. A pressure of 1 atmosphere (equivalent to 15 psi) was applied to the roof slab and within the stair well below the access hatch. With a buried structure the pressure wave is attenuated as it passes through the soil and a factor of 0.5 has been assumed in this case. The effect is to give a pressure load of ½ atmosphere (7.5 psi) applied horizontally to the external face of all the walls.

The results for each load are computed and printed out separately for each node and member in the structure. The results for specified combinations of load are also

computed. By having the results for each individual load available it is possible to examine the effects of changing the combinations and varying the intensities of load.

The results for three load cases have been plotted on drawings of the structure:
(a) Fig. 40 – *Load Case 1.* Static overpressures of 1 atmosphere and ½ atmosphere applied as described in (e) above.
(b) Fig. 41 – *Load Case 2.* 'Wet' soil and blast. All the loads described above, including buoyancy due to saturated soil.
(c) Fig. 42 – *Load Case 3.* 'Dry' soil and blast. As Case 2 but excluding soil buoyancy.

The drawings show values for computed bending moments at each node in each diagram.

Computer analysis - dynamic 3.3.4

It would be expensive to apply a dynamic analysis to the complex static model; fortunately, it is not necessary. Satisfactory results for the dynamic behaviour of the structure can be derived from a much simpler model.

A box-like model with 26 nodes and 48 members was set up for the analysis. This is shown on Fig. 39 The model was then analysed on the complementary program to LEAP for dynamic analysis — DEAP.

The mass of the structure is lumped at the nodes. The supports are modelled to simulate the elastic and damping characteristics of the soil using a procedure described in the CIRIA Report URS, *Dynamics of Marine Structure* Chapter 3.

It is necessary to know the shape of the time-history curve of the blast pressure wave. For this analysis the curves in *Introduction to Structural Dynamic* Biggs J. M. page 277, have been used. The curves are reproduced on Fig. 39.

When an explosion occurs, a circular shock front is propagated away from the point of burst. At any instant of time the distribution of overpressure (the excess above atmospheric pressure) along a radial line is as shown in Fig. 42 *(Fig. 1).* The shock front travels with a velocity 'U' and has a peak pressure p_{so} which decays behind the front. At a fixed point on the ground the variation of overpressure with time is indicated in Fig. 42 *(Fig. 2).* There is also a dynamic pressure effect due to the kinetic energy of the air mass but this does not affect underground structures.

The DEAP program applies the time-history of the pressure wave at a series of equally spaced times over one cycle of input. Moments, shears and deflections are plotted for each node and in addition the program can provide: relative amplitude of the dynamic spectrum, resonant frequencies, Eigen values, and velocities.

The results are compared with the static load case 1, for positions at the supports and mid-spans of the walls and slabs.

The magnification factors are different for each position but in this analysis a global factor of 1.5 could be deduced. The factor is applied to the overpressure fraction of the load combinations to give total 'dynamic' moments.

Design values 3.3.5

In Figs. 41 and 42, moments have been plotted at each node for the two combination load cases under 1 atmosphere overpressure. The maximum values for span and support moments have been indicated thus: 21.5

These maximum values have been re-plotted in Fig. 43. At each of the critical nodes there are shown four values. It was decided that designs were required for the '1 atmosphere' shelter and for a '3 atmosphere' shelter. It was a simple matter to factor up the overpressure fraction of each moment to give the series of values as follows: static due to 1 atmosphere, dynamic due to 1 atmosphere, static due to 3 atmospheres, dynamic due to 3 atmospheres. All the values are for the full combinations of loading.

These moments are then used to calculate the required reinforcement in the structure. A similar series of drawings could be produced for the shear values.

3.3.6 Reinforcement design

The moments etc. calculated by the computer program are on an elastic basis, but it is intended that these structures carry the applied blast loadings at near calculated ultimate capacities, i.e. as plastic members, and this is the basis for the hand analysis approach of, for example, Biggs.

It is necessary to allow for plasticity in using the tabulated values and in this analysis a re-distribution of 20 per cent of the moment from support to mid-span has been used.

The reinforcement has then been designed using the CP110 ultimate limit state method.

The use of load factors for this type of loading is the subject of some debate. The American Concrete Institute in their journal ACI 349-76 recommend a factor of 1.2 for blast loads. The minimum load factor in CP110 — for accidental loading — is 1.05. It can be argued that for an arbitrary, but precisely defined, pressure load a factor of 1.0 would be satisfactory. In this example the ACI figure of 1.2 has been used.

The ACI also specify 'dynamic material strength increase factors' and these have been used, viz:

High yield reinforcing steel, bending	1.10
Mild reinforcing steel, bending	1.20
Concrete	1.25

Using these factors and the CP110 approach, two sets of reinforcement drawings have been produced.

Fig. 36 is for 1 atmosphere overpressure and Fig 37 for 3 atmospheres.

In order to give standardisation of design, the reinforcement size and spacing is suitable either for the six-person shelter which was analysed, or the 'stretched' twelve-person shelter.

Shear capacities of the sections were checked by the CP110 method, but using an average permissible shear stress of 0.04 x fcu x dynamic strength increase factor (1.25) x 0.8. The factor of 0.8 is to comply with the recommendation of the ACI that shear strength should exceed flexural strength by 20 per cent. The higher permissible shear stresses derive from the results of experimental tests on the shear strength of reinforced concrete members under dynamic loadings.

3.3.7 References

LEAP *Linear Elastic Analysis Program*
DEAP *Dynamic Elastic Analysis Program*
by Computer Consortium Services Limited
5 Windmill Street, London W1P 1HF

Introduction to Structural Dynamics J. M. Biggs
Published by McGraw-Hill

Dynamics of Marine Structures Report UR8
Published by CIRIA Underwater Engineering Group
6 Storey's Gate, London SW1P 3AU

ACI 349-76 *Nuclear Concrete Structures*
Appendix C (Journal of the American Concrete Institution, Volume 74, February 1977)

CP110 : 1972 *The Structural Use of Concrete*
British Standards Institution

Fig. 36 *Reinforced concrete details. Shelter design for blast effects of 15 psi peak overpressure (1 atmosphere)*

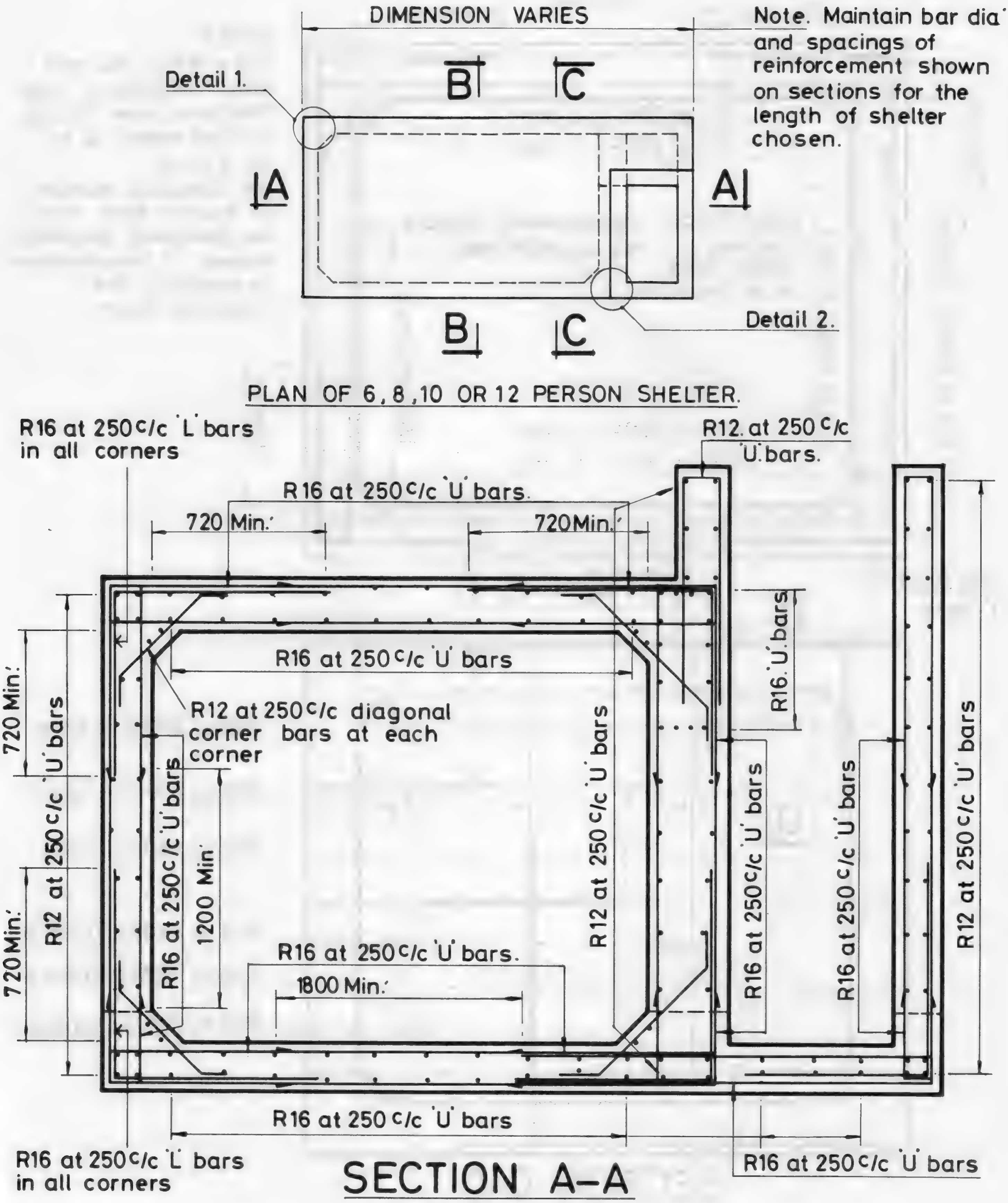
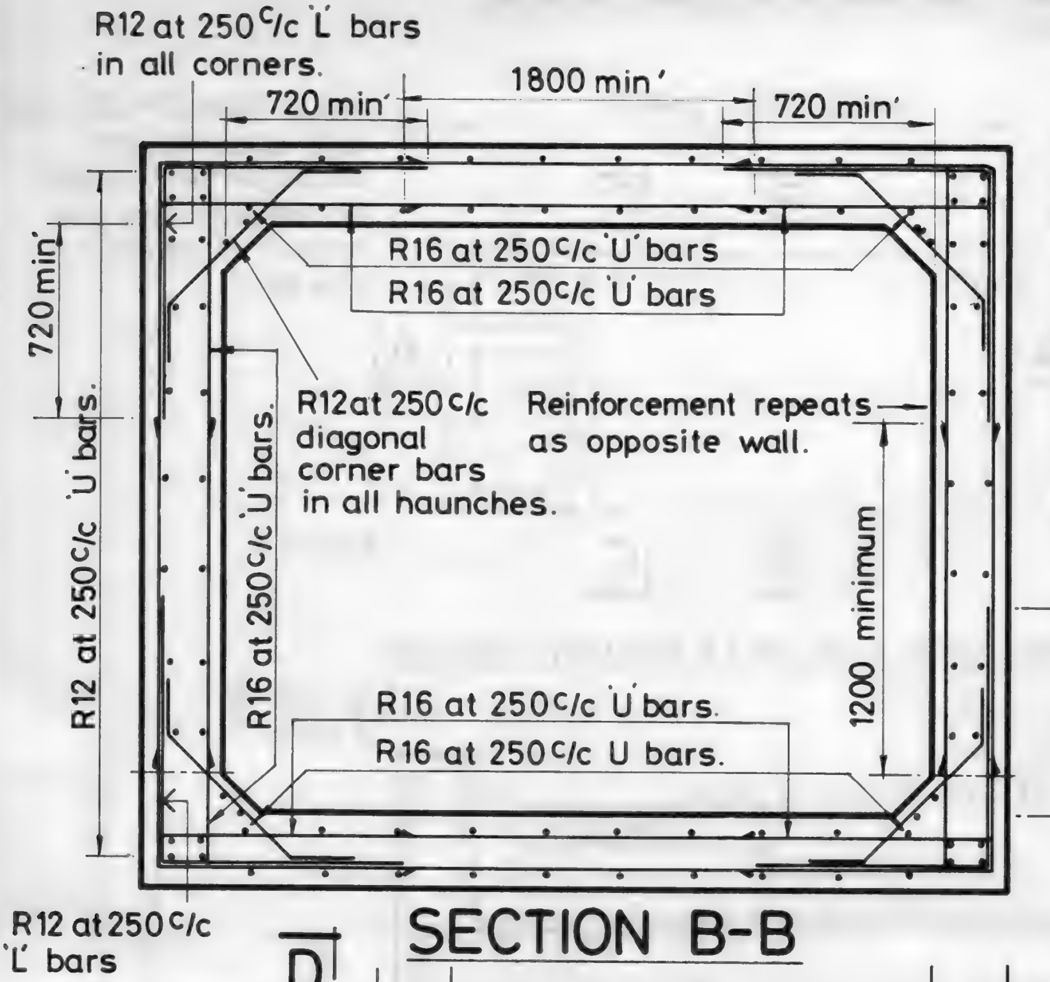
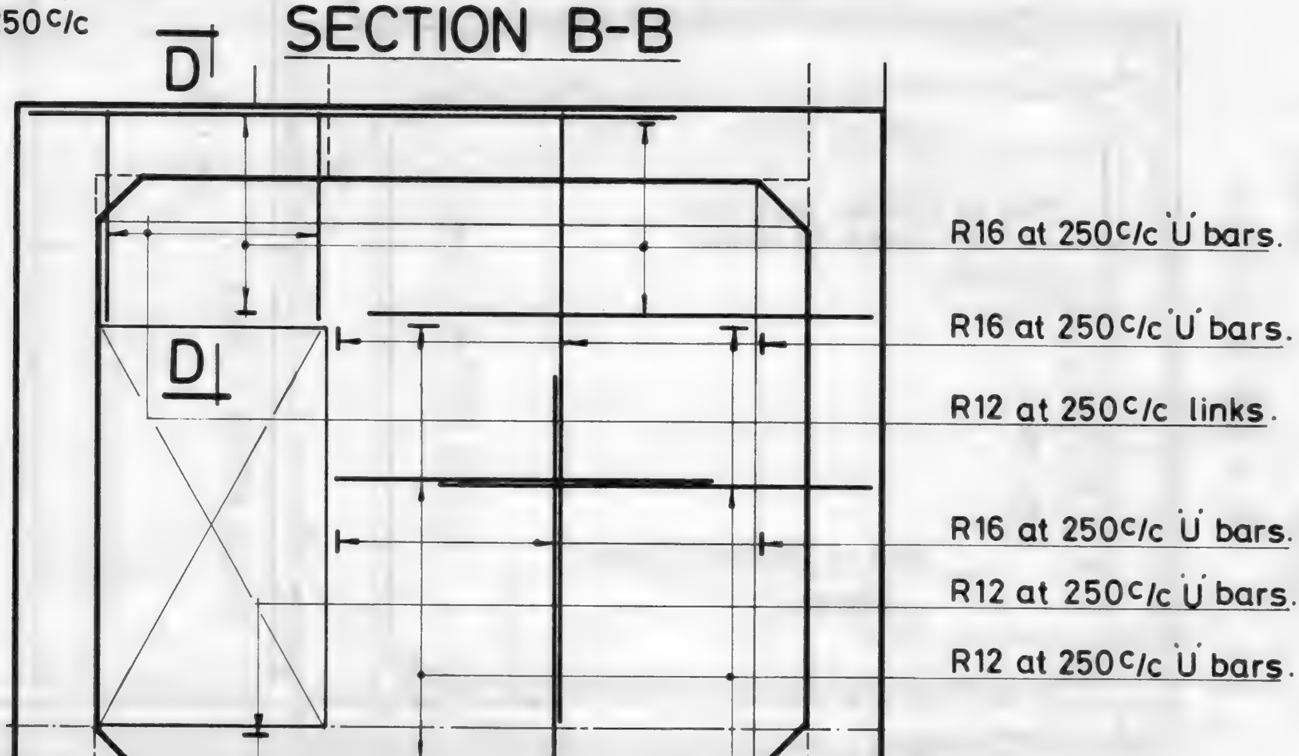


Fig. 36 *(continued)*



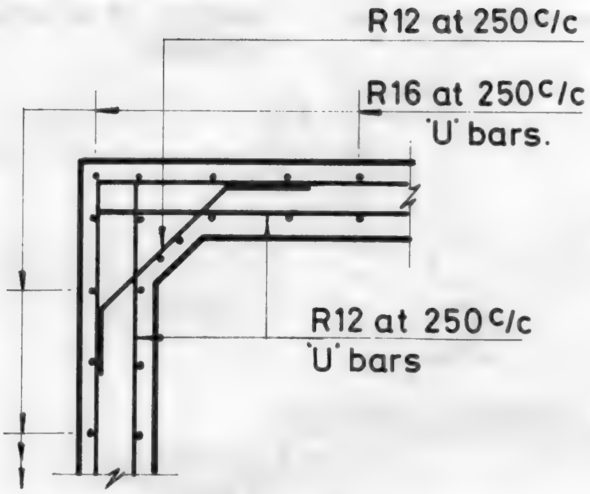
SECTION B-B

NOTES
R16 = 16 mm dia mild steel reinforcing rods.
Minimum cover to any reinforcement is to be 50 mm.
An adequate number of spacer bars is to be provided between layers of reinforcement to maintain the required cover.

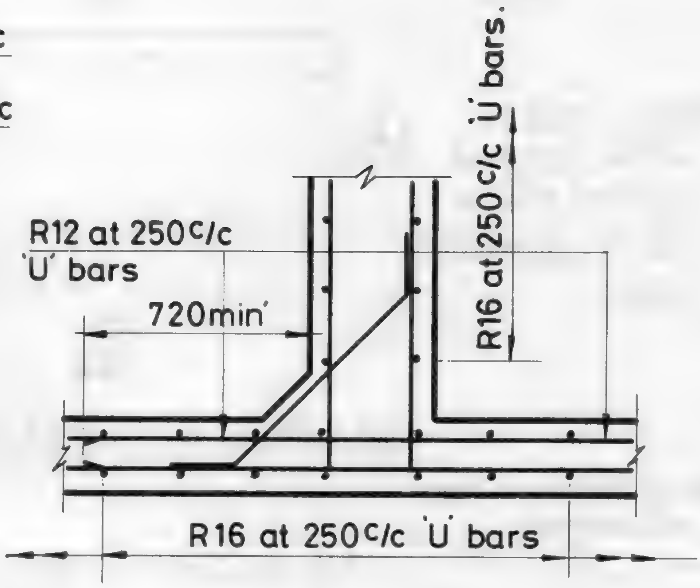


SECTION C-C

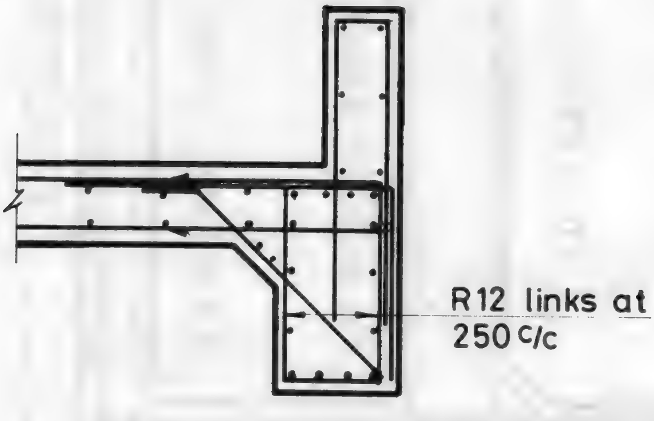
Fig. 36 *(continued)*



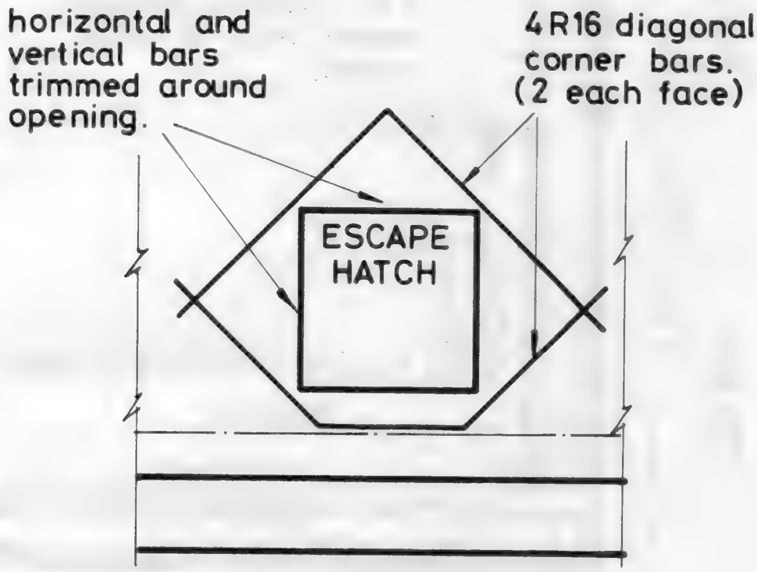
PLAN DETAIL 1
(TYPICAL CORNER)



PLAN DETAIL 2



SECTION D-D



ELEVATION OF ESCAPE
HATCH IN WALL.

Fig. 37 *Reinforced concrete details. Shelter design for blast effects of 45 psi peak overpressure (3 atmospheres)*

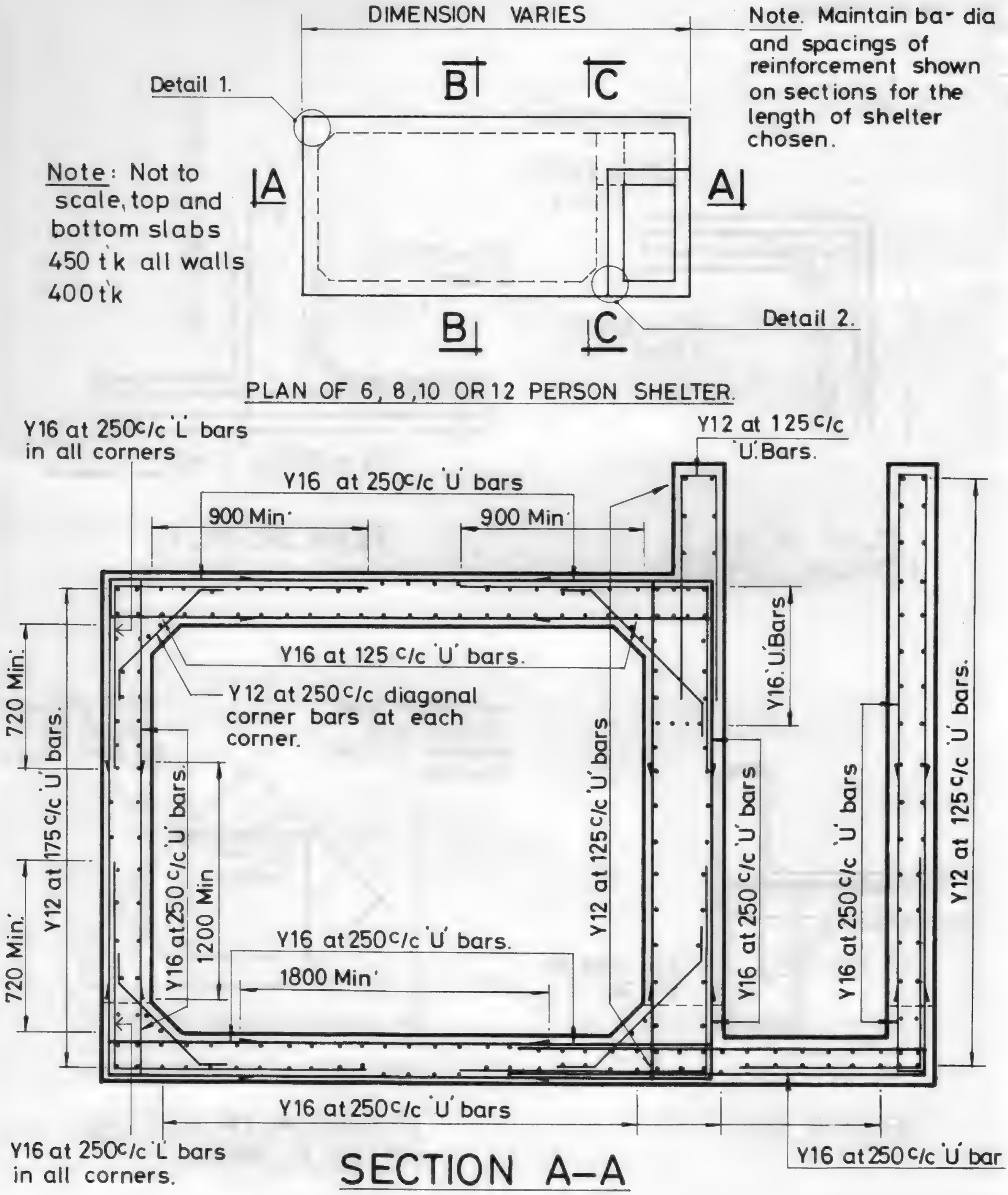
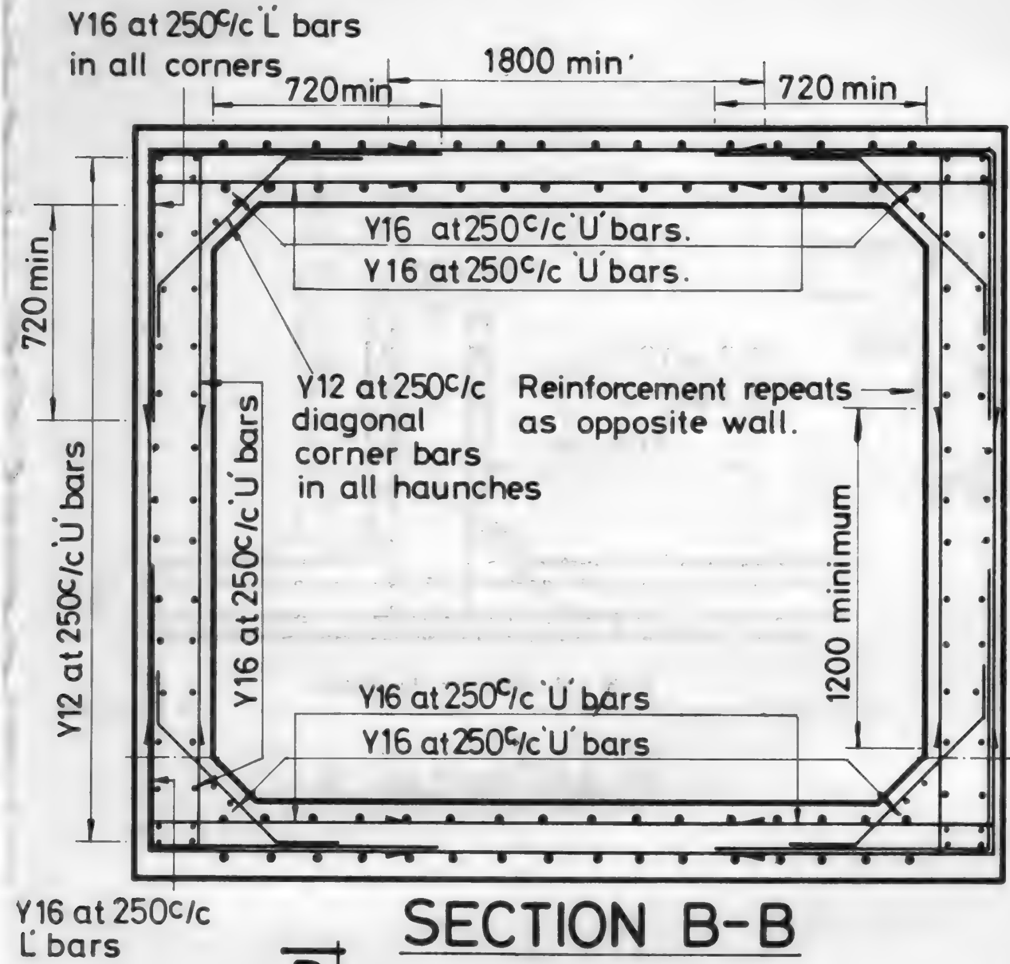


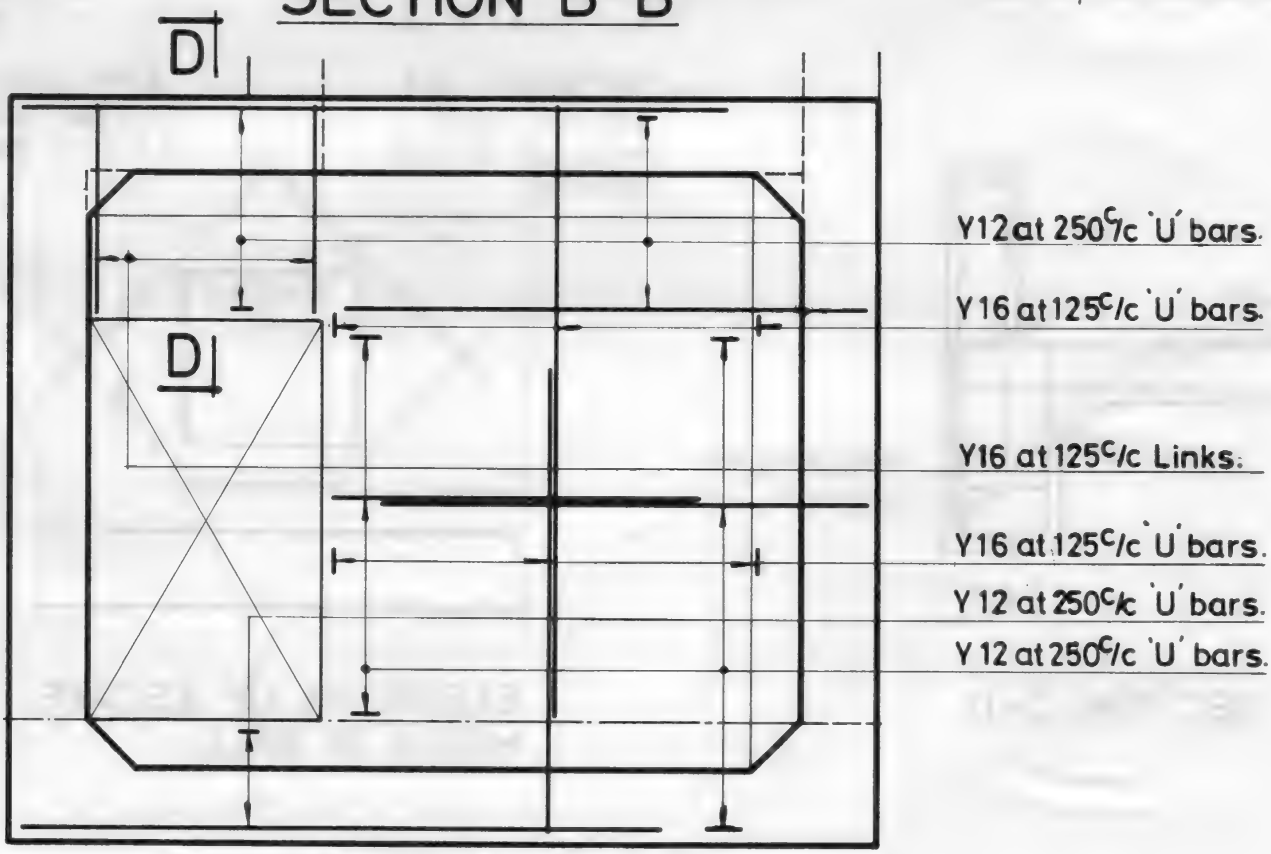
Fig. 37 *(continued)*



SECTION B-B

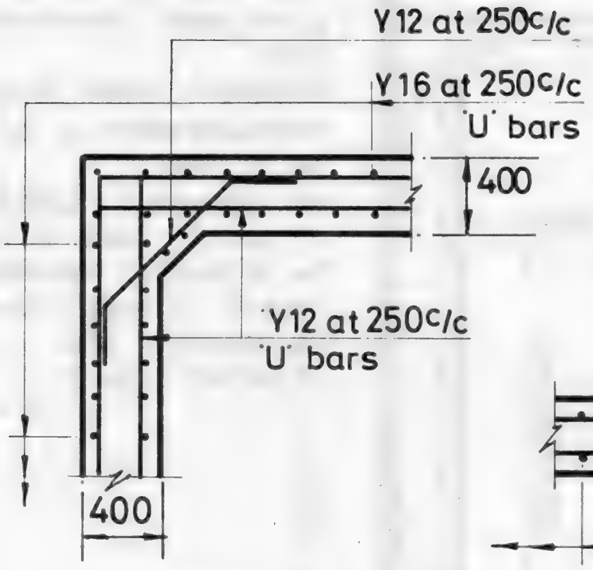
NOTES.
Y20 = 20mm. dia high yield steel reinforcing rods
Minimum cover to any reinforcement is to be 50 mm.
An adequate number of spacer bars is to be provided between layers of reinforcement to maintain the required cover.

Note:
Not to scale
top and bottom slabs 450 tk, all walls 400 tk.

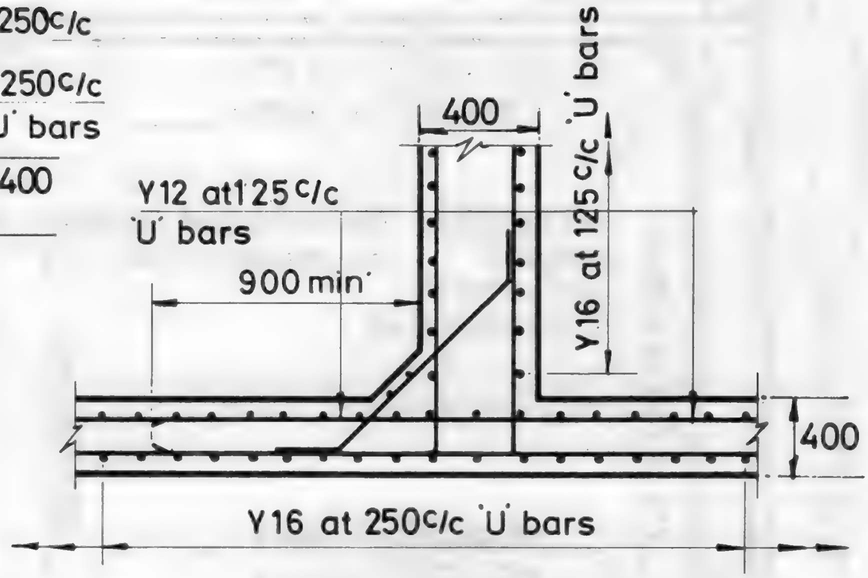


SECTION C-C

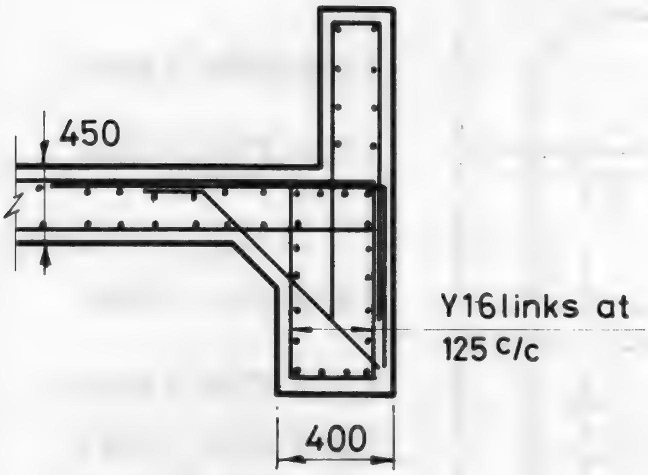
Fig. 37 *(continued)*



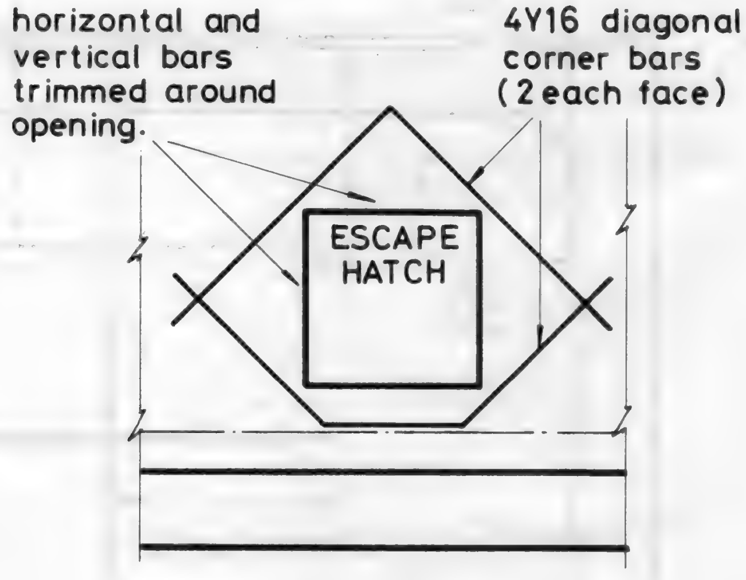
PLAN DETAIL 1
(TYPICAL CORNER)



PLAN DETAIL 2



SECTION D–D



ELEVATION OF ESCAPE
HATCH IN WALL.

Fig. 38 ***6-person family shelter: general arrangement***

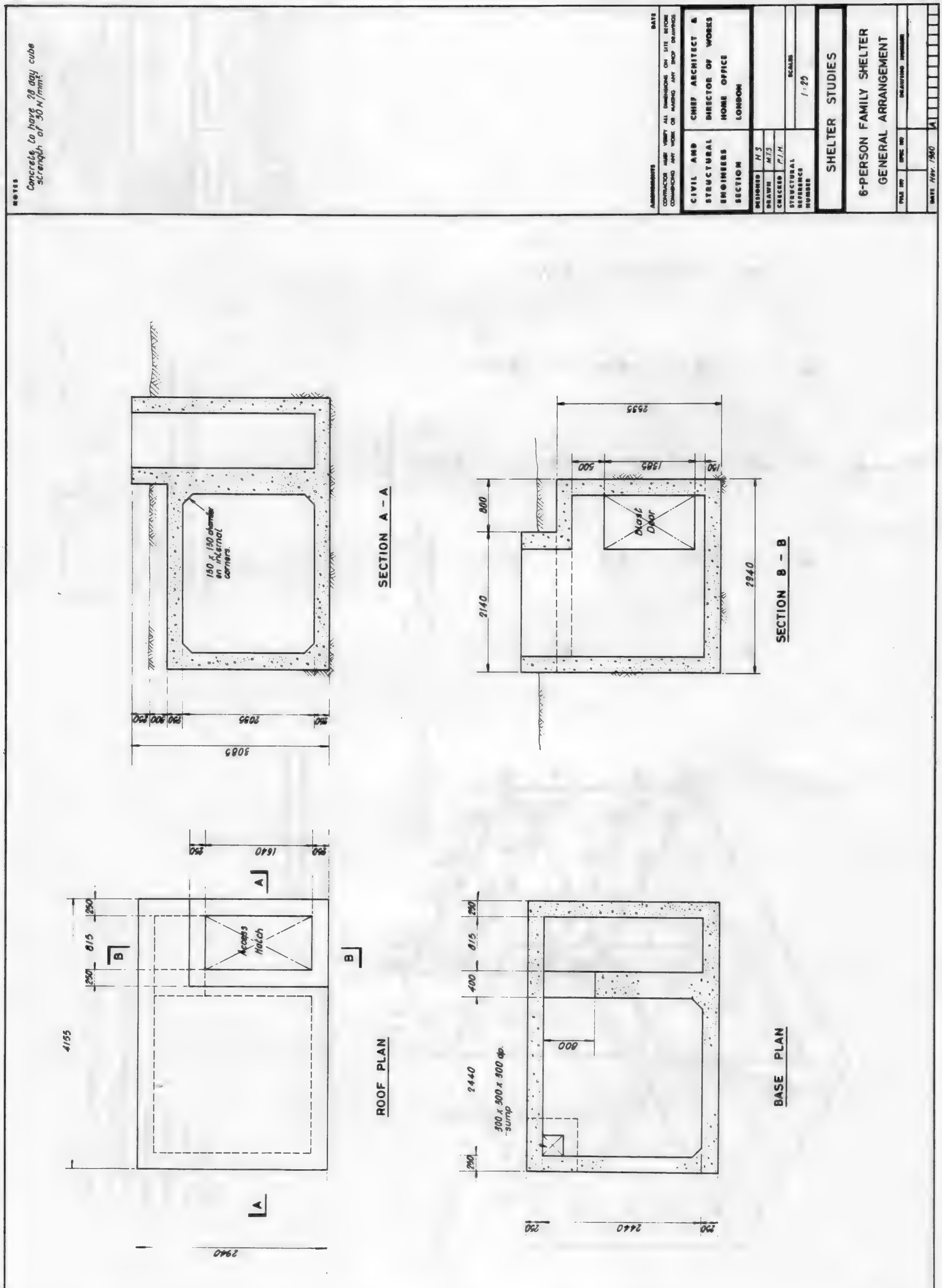


Fig. 39 ***Static and dynamic computer models***

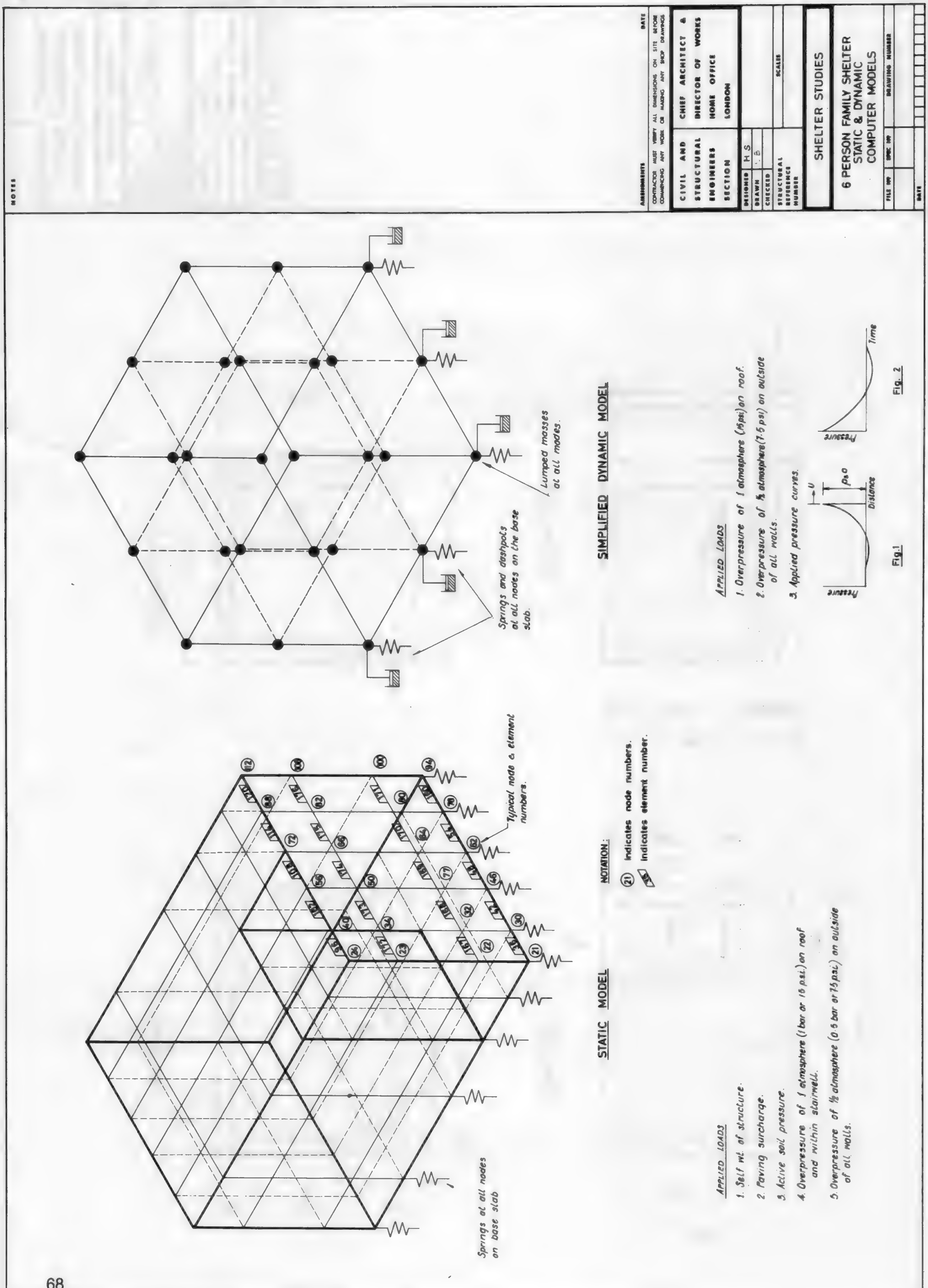


Fig. 40 ***Static analysis, load case 1***

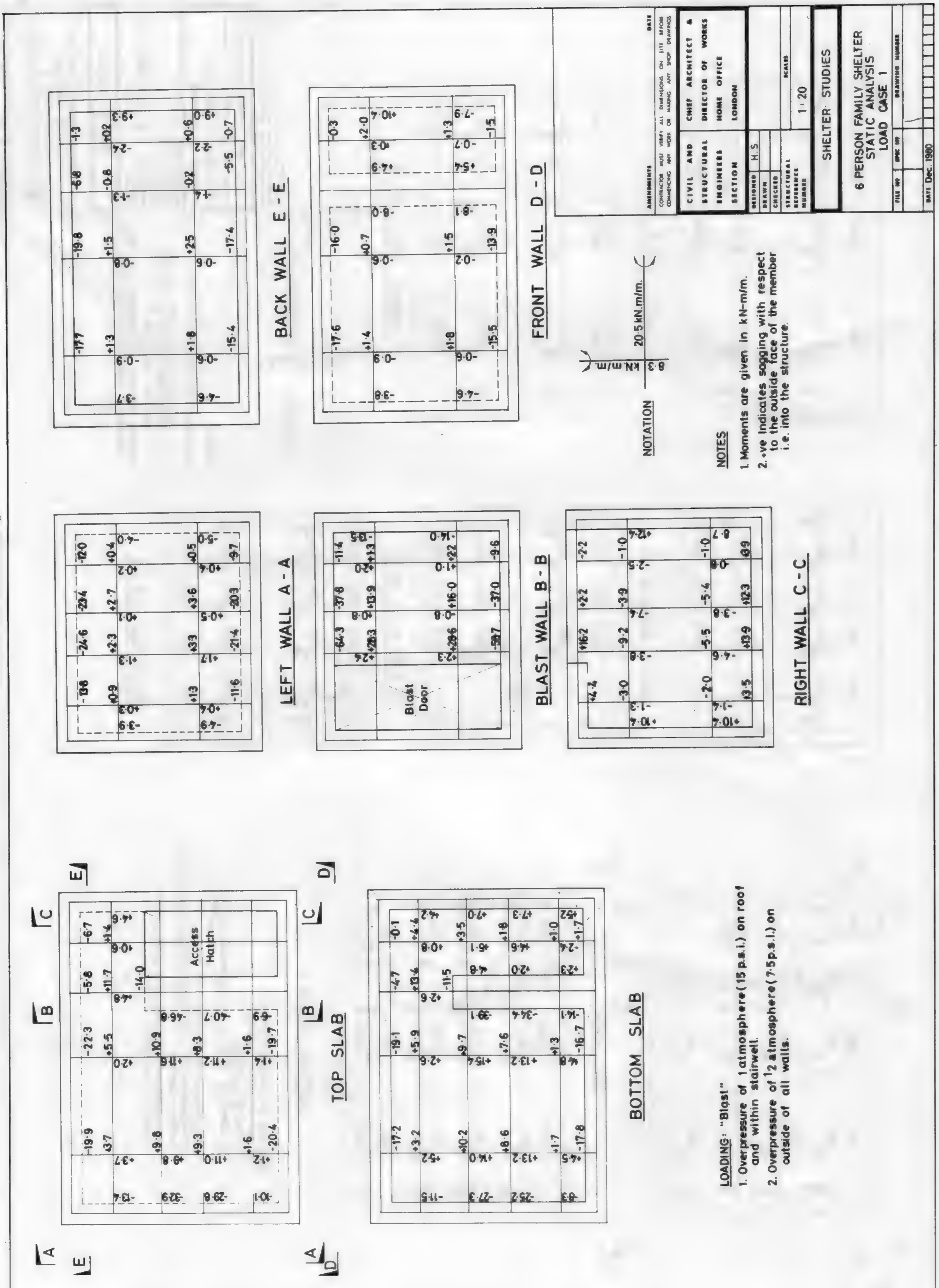


Fig. 41 *Static analysis, load case 2*

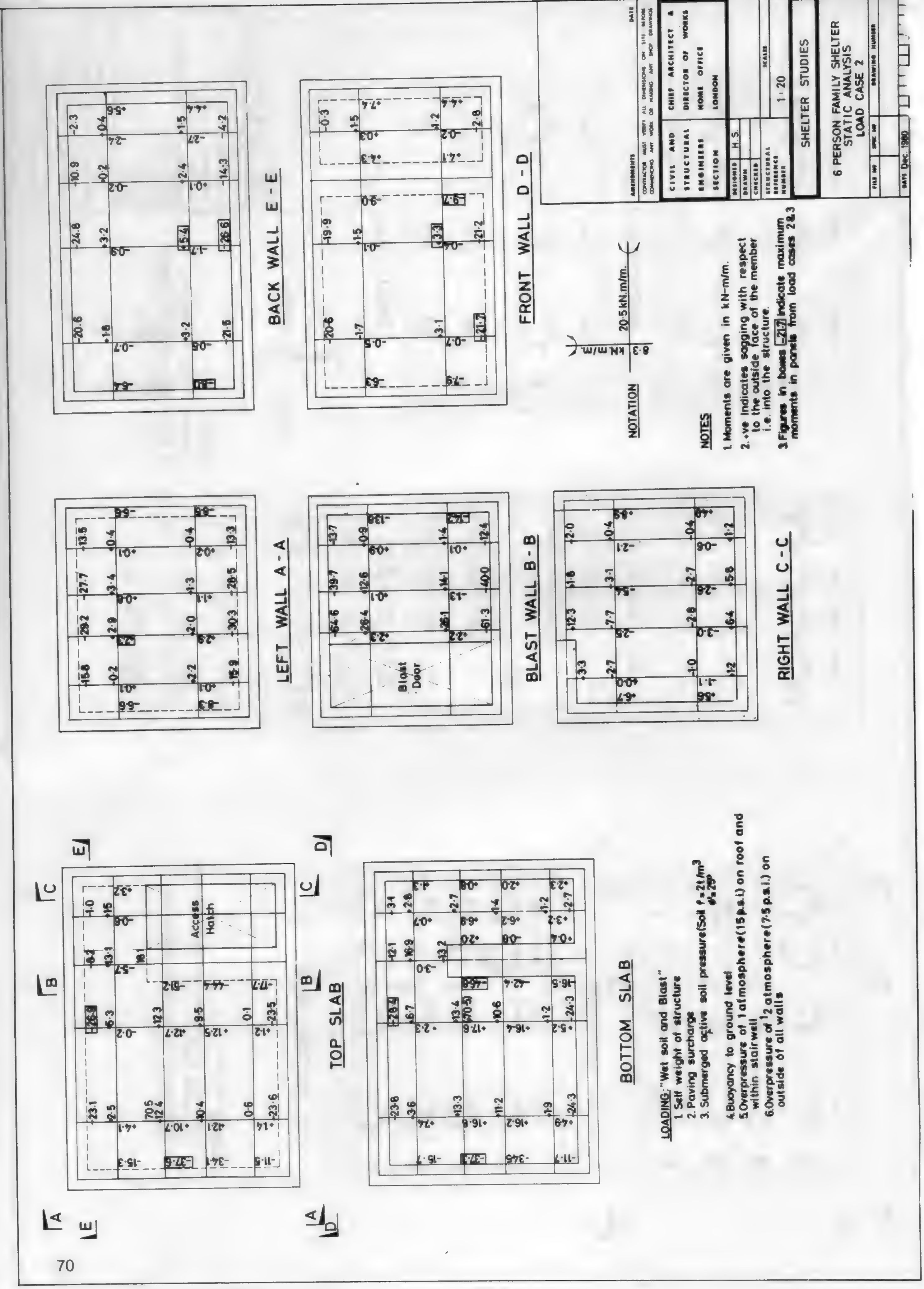


Fig. 42 Static analysis, load case 3

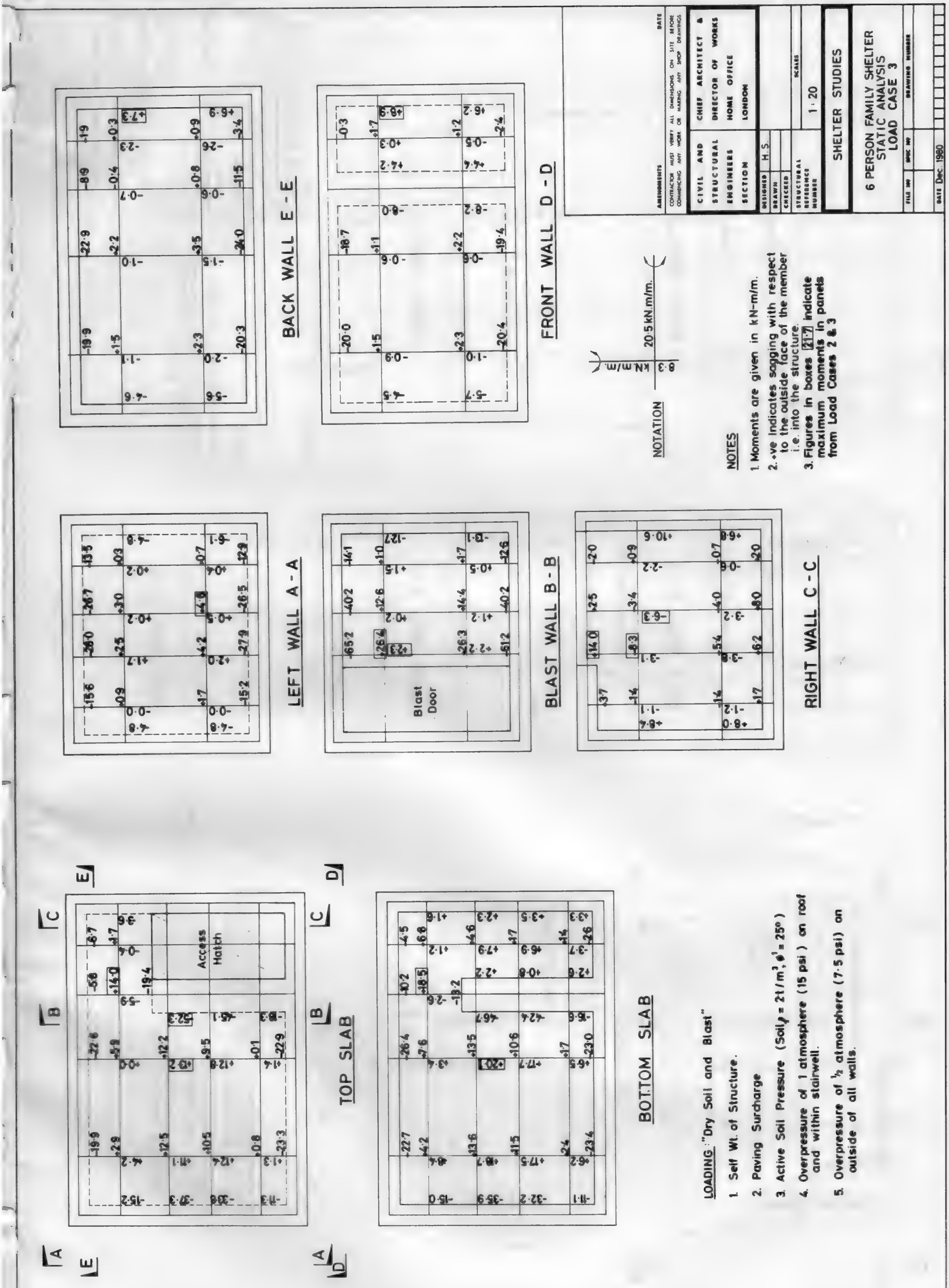
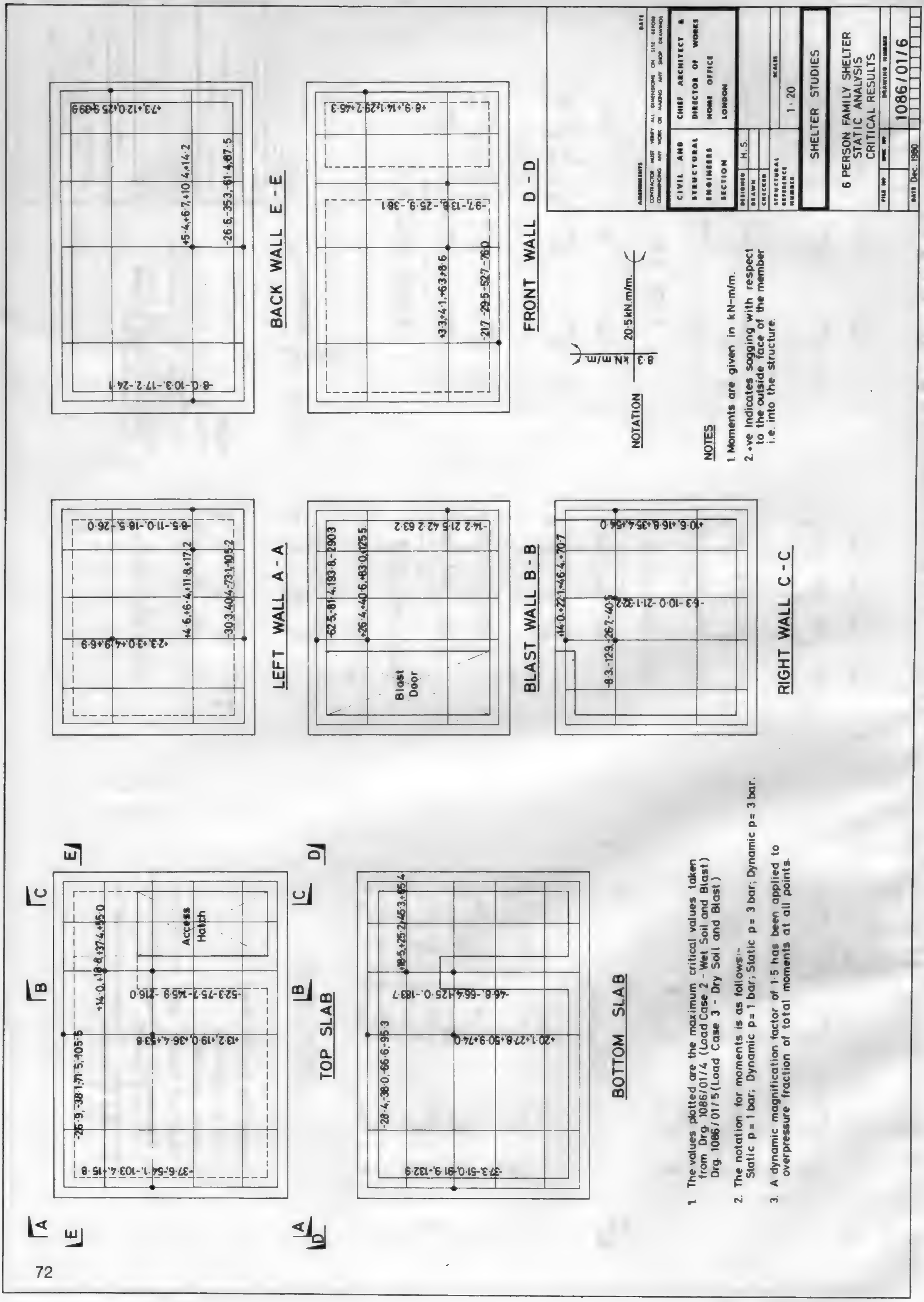


Fig. 43 *Static analysis, critical results*



Federal Civil Defence Administration Report WT-801		Effects of Atomic Explosions on Home Shelters (Includes Displacement, etc. of Models).
A.W.R.E. Report T43/58 Nov. 1958.	Secret/Atomic U.K. Eyes Only	Operation Antler. The Remote Measurement of the Variation with Time of Gamma Dose Rate from Fallout.
E.R.D.L. Fort Belvoir Virginia Report 1468-TR 2nd November, 1956	Secret/ Restricted Data	Field Fortifications Test Exercises. Desert Rock VI. N.J. Davis Jr.

Chapter 4

Two designs for improvised shelters

4.1 Easily-constructed improvised garden shelter using household materials

This shelter is suitable for areas where underground shelters are impracticable, for example, where there is a high water table, so that a deep hole fills with water. It can be constructed using only materials which are generally available, and could be ***built in a time of crisis***. It would take two people about 24 working hours to build.

The shelter consists of a shallow trench dug into the ground with a roof of doors or sheet timber that is supported above ground level by earth walls. The structure is then covered by at least 450mm of earth.

This basic design will give good protection from fallout radiation particularly if the occupants keep away from the entrance area. If, in addition, a barrier of sandbags or packed soil is built about two feet in front of the entrance, and to the same height, the protection in the entrance area will be improved.

Construction

1. Select a site on level ground where there is little chance of rainwater collecting.

2. You will need:

   i. Pick, shovel or spade (preferably both), wheelbarrow or buckets, saw, screwdriver, knife, tape measure, pencil and paper, and a pair of gloves.

   ii. Pieces of large sheeting material, e.g. carpets, blankets, sheets, heavy duty polythene, sacking etc., for making earth rolls (Fig. 47).

   iii. Plastic bags or pillowcases for making sandbags.

   iv. Timber: pieces of 50mm x 100mm wood at least 1000 mm long are most useful although any suitable strong timber could be used for the cross braces (Fig. 46). Floor-boards about 1200mm long could be used for entrance and exit tunnels (Fig. 52).

   v. Nails: 100 x 50mm steel nails
   30 x 100mm steel nails

   vi. Doors: One robust door (normally about 750 mm wide) per person is required together with one door each for entrance and exit. Fittings such as handles should be removed. If you do not have enough doors, sheet timber can be used. Likewise, less substantial (particularly interior) doors would require additional sheet timber to achieve the necessary strength.

   vii. Rainproofing material to cover the doors, e.g. polythene sheeting, shower curtains and vinyl floorcovering.

   viii. Pegs and string for markers and tying sandbags.

3. Construct the shelter as shown in Figs. 44–54.

4. If, in addition, a barrier of sandbags or packed soil is built about half a metre in front of the entrance, and to the same height, the protection in the entrance area will be improved.

5. Furnish the shelter as required.

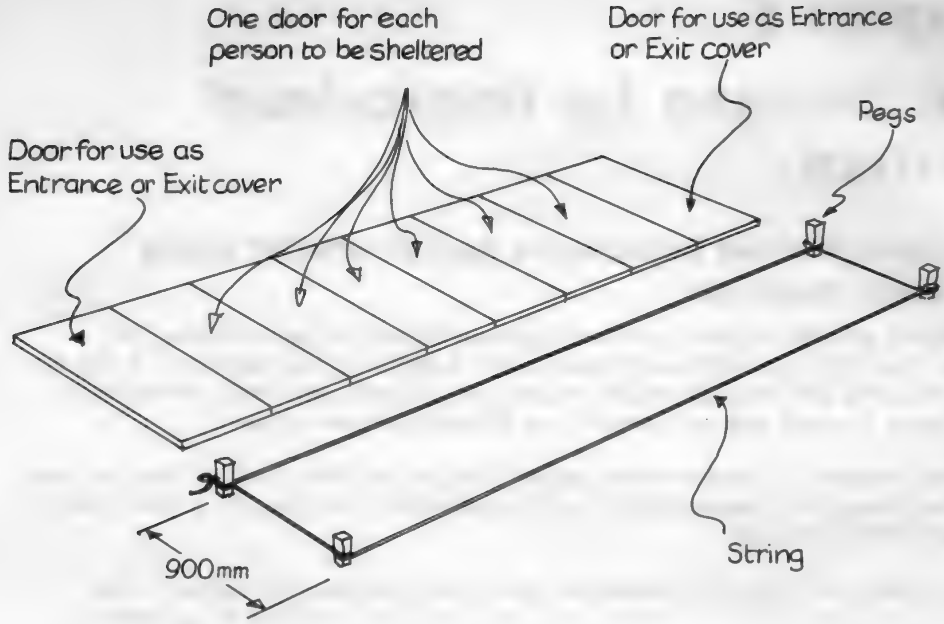


Fig. 44 ***Mark out trench***

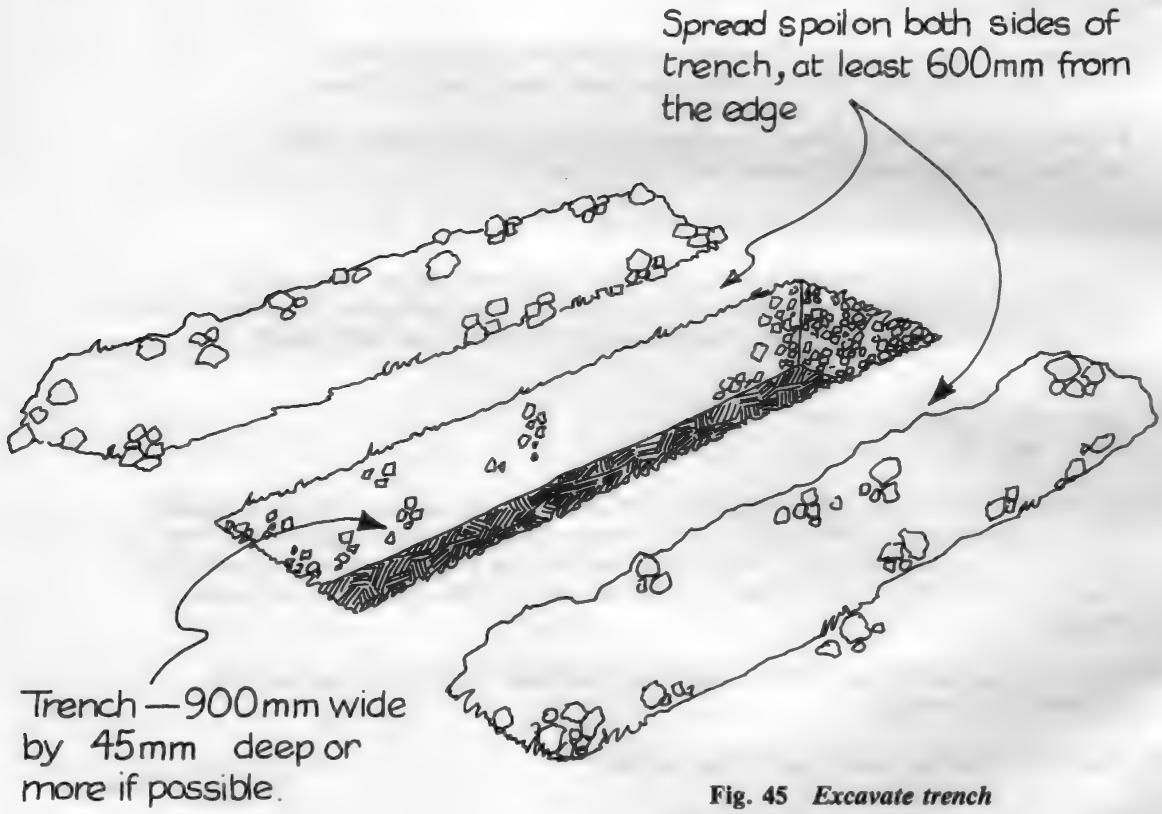


Fig. 45 ***Excavate trench***

Fig. 46 ***Construct temporary walls***

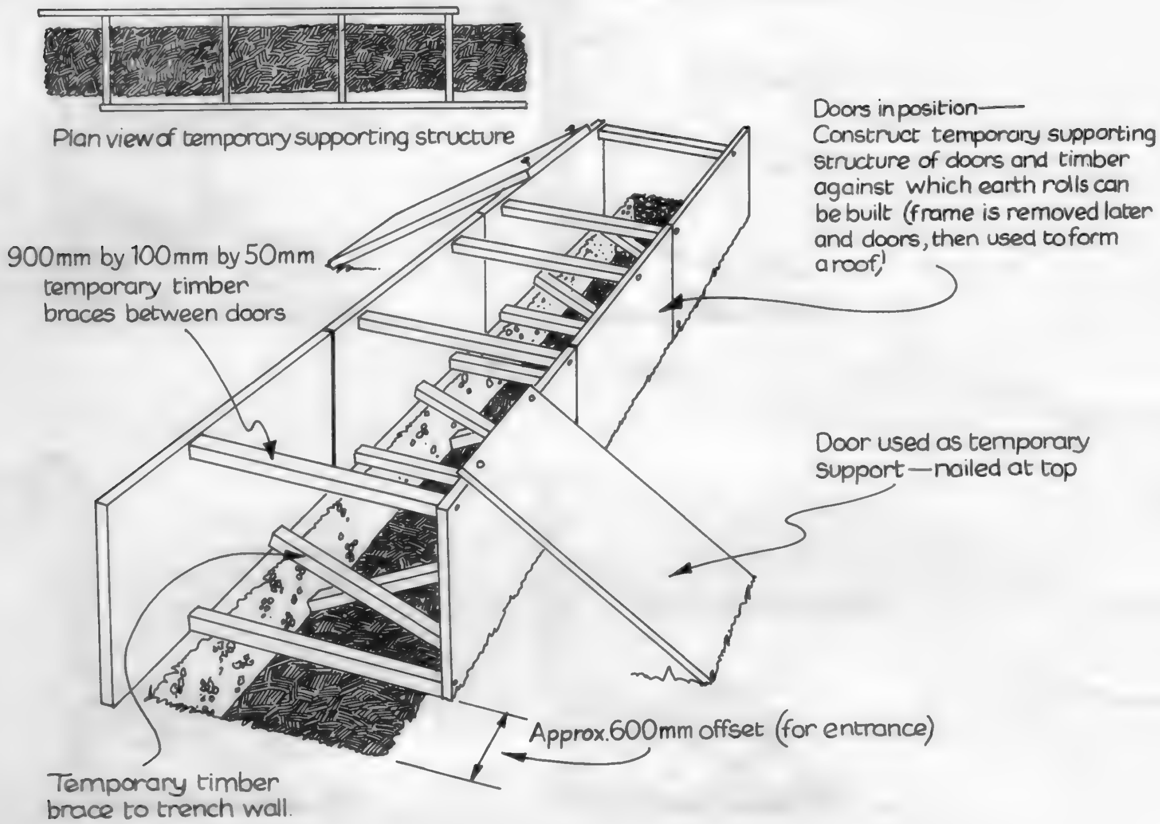


Fig. 47 ***Position sheeting material***

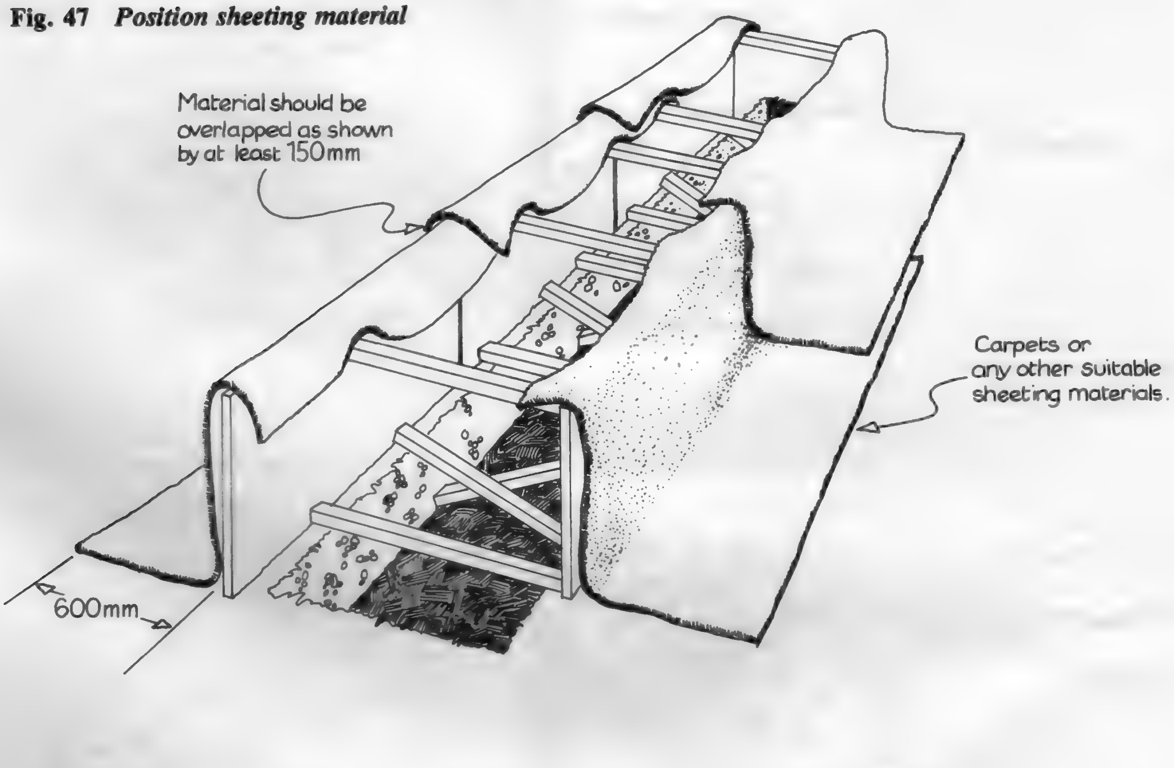


Fig. 48 ***Construction of earth rolls***

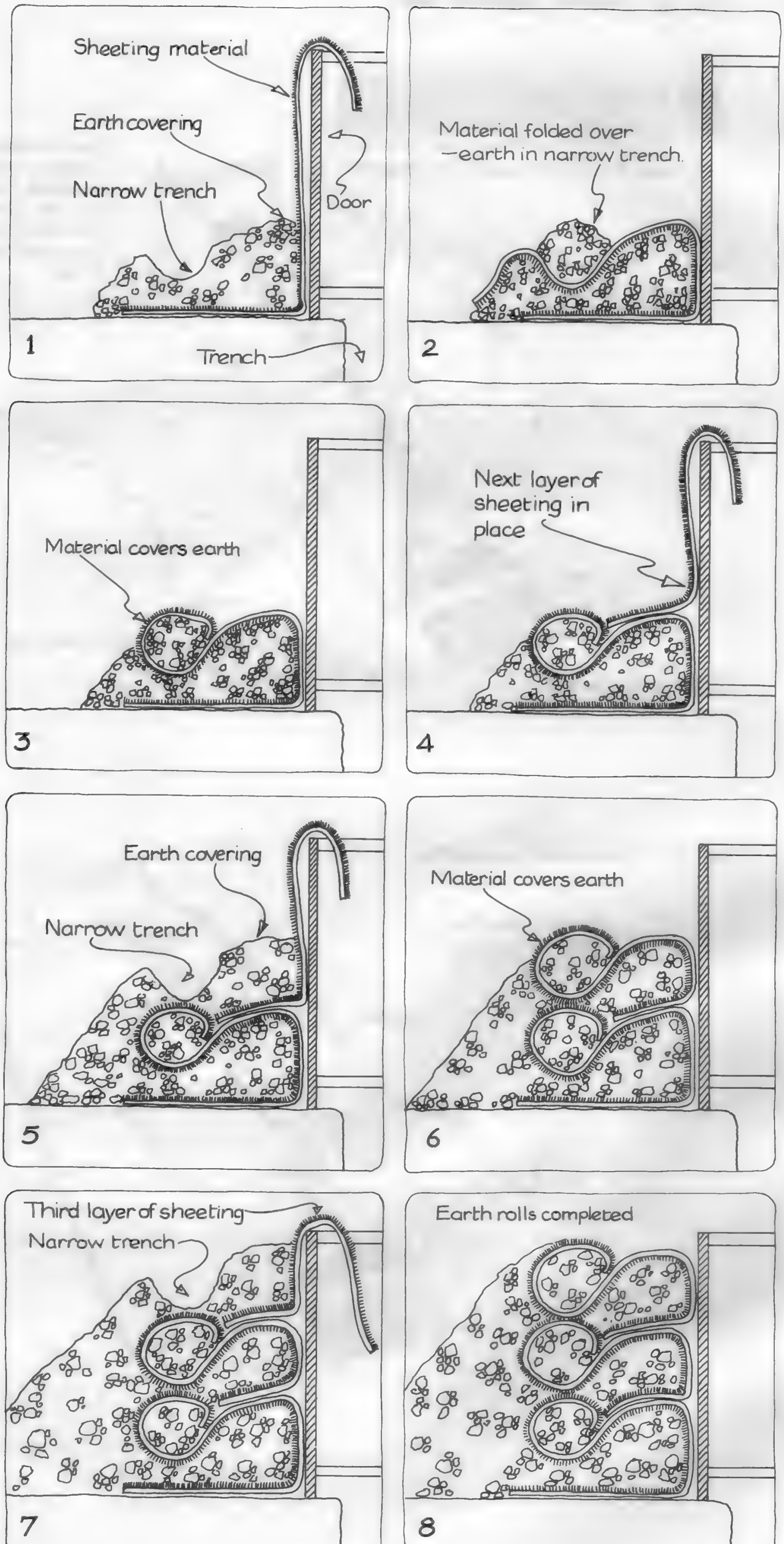


Fig. 49 ***Remove temporary walls***

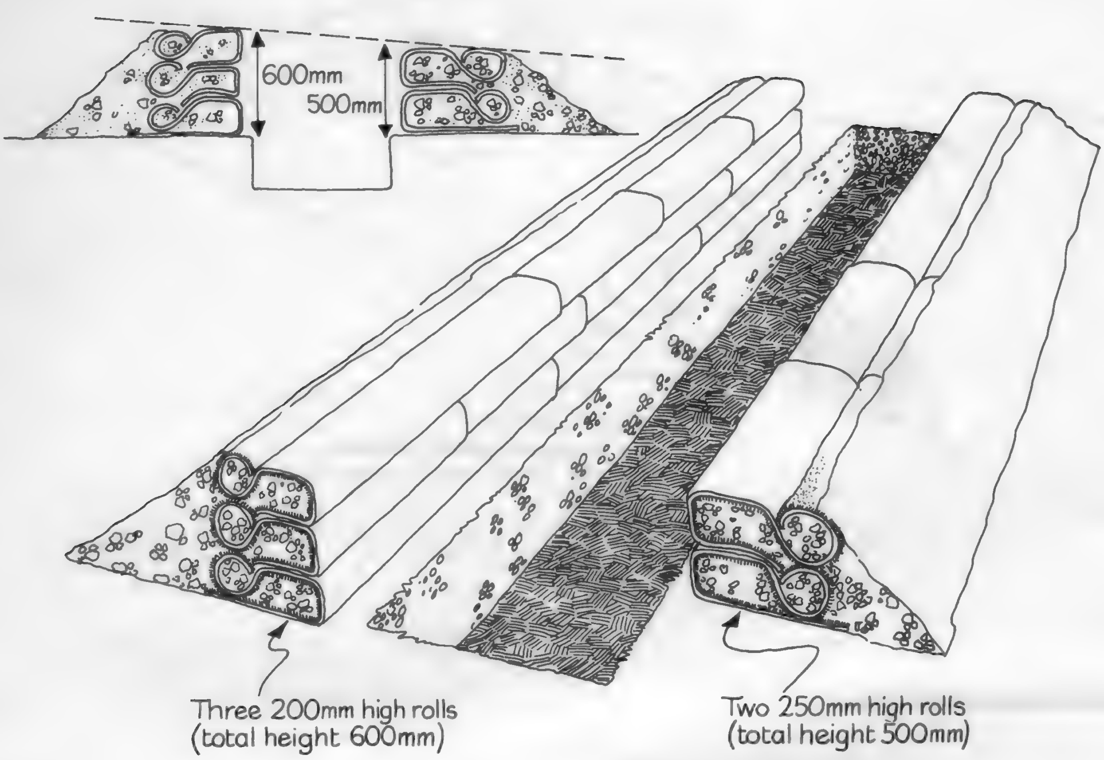


Fig. 50 ***Construct entry/exit frames***

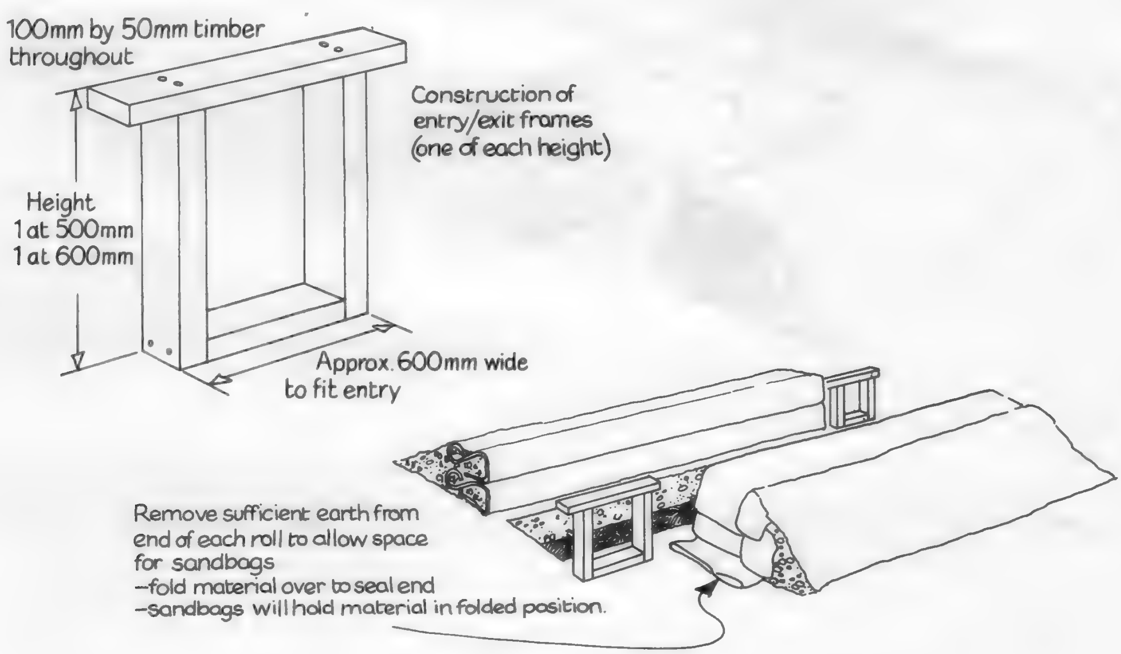


Fig. 51 *Construct end earth rolls*

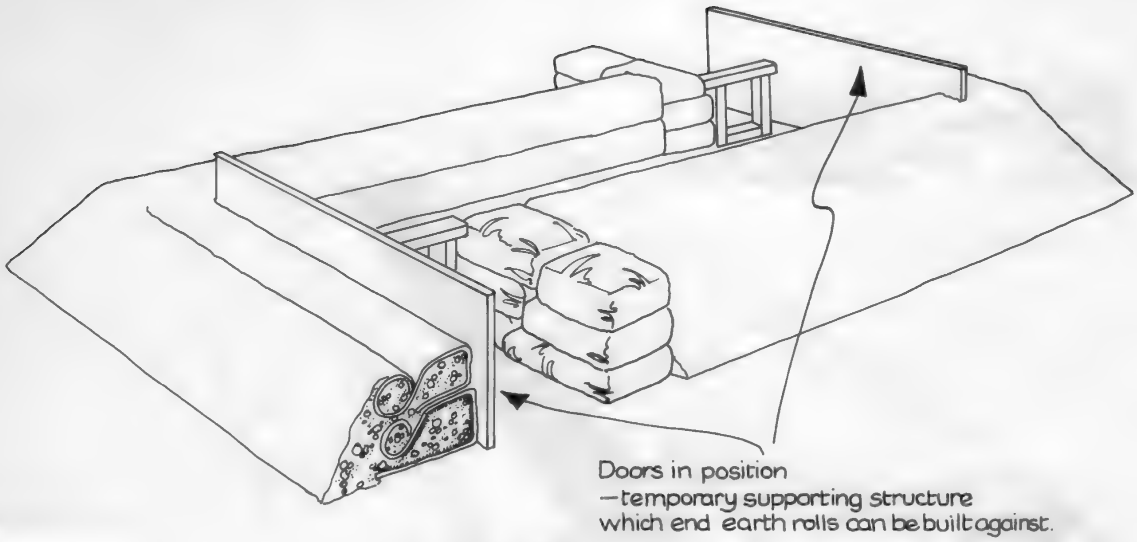


Fig. 52 *Assemble entrance/exit covers*

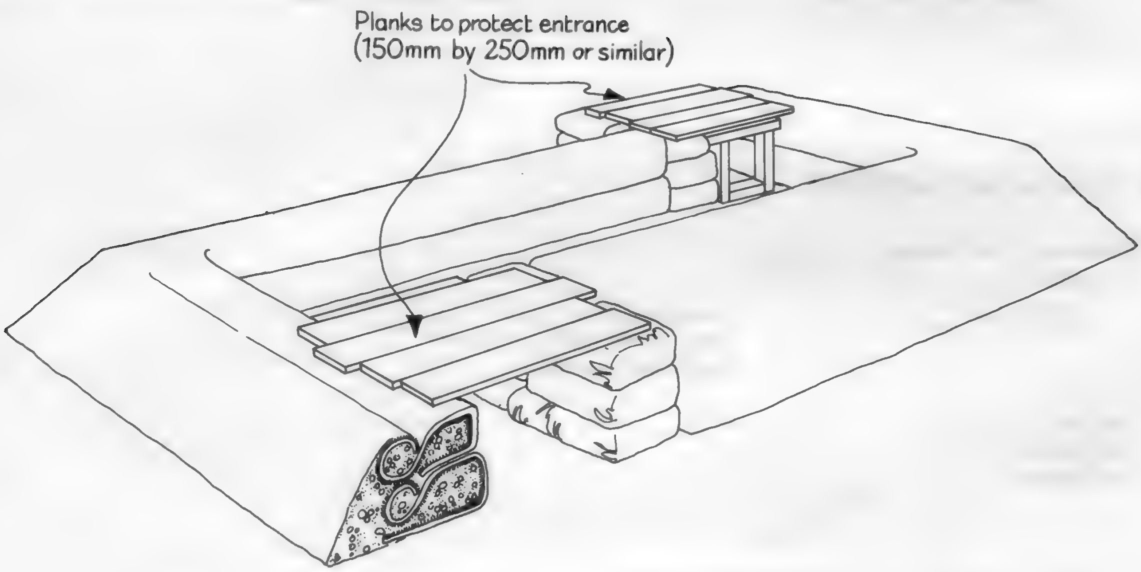


Fig. 53 ***Position doors and waterproof cover***

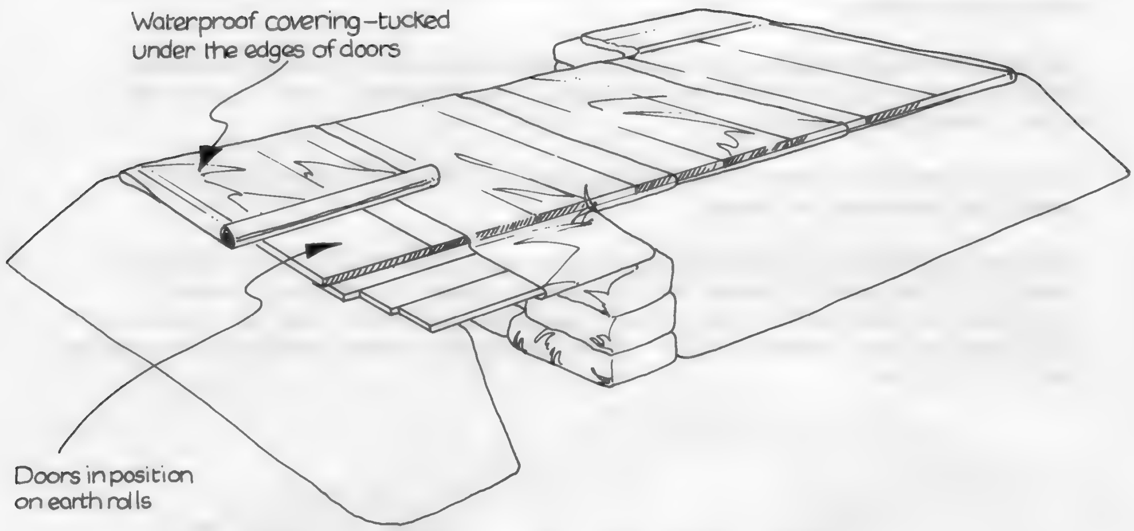
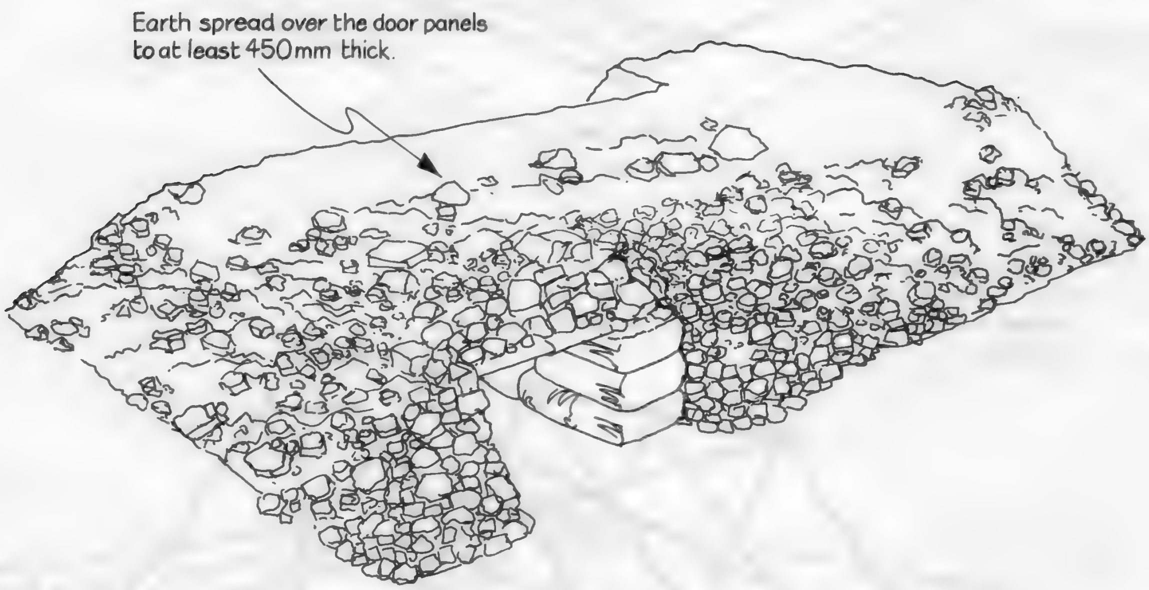


Fig. 54 ***Finish structure with earth cover***



4.2 Improvised outdoor shelter using do-it-yourself materials

The following diagrams show how a basic shelter can be constructed from standard scaffold poles and other materials available from builders merchants, timber yards and do-it-yourself stores.

This type of shelter could be constructed in a time of crisis from materials previously purchased and stored. It would take two people about 24 working hours to build this shelter – the size is adaptable.

The dimensions given would accommodate a family of four for a short period or two people plus provisions for longer.

This shelter uses steel or alloy, standard diameter scaffold poles. These are arranged in a series of 'A' frames over a trench. It is necessary to brace the frames with further scaffolding both diagonally along its length and across the waists of the 'A' sections to give rigidity. In both cases proprietary clamps are the best method of securing the scaffold poles to each other.

Fig. 55
Prepare a trench 2.5 m x 2.5 m and at least 450 mm deep. Line it with heavy duty polythene sheeting. Lay a floor of two sheets of plywood, 19 mm thick and 1.25 m x 2.5 m.

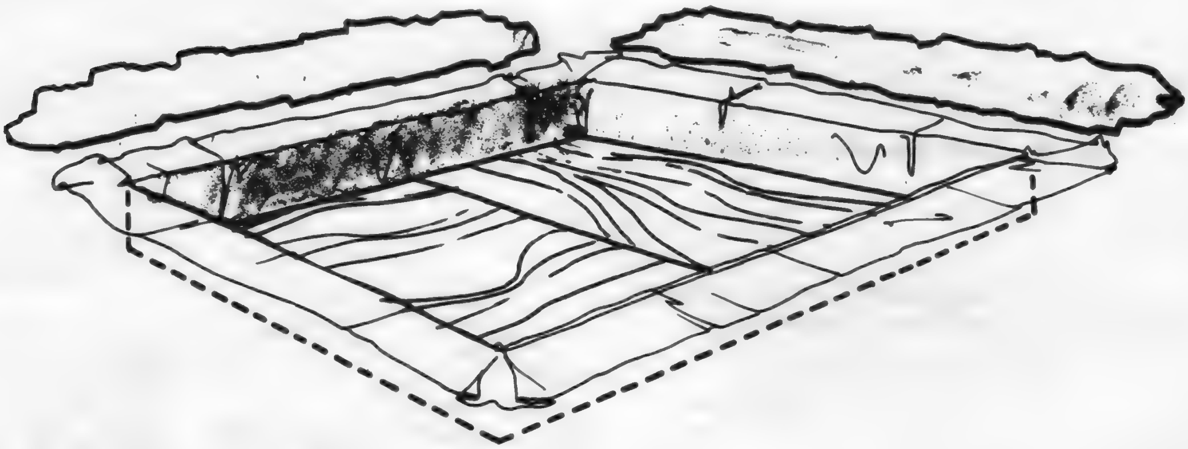


Fig. 56
Construct the frame of scaffold poles (or you could use wood). This should be as strong as you can make it. You can increase the strength with vertical and diagonal bracing, or crossbars.

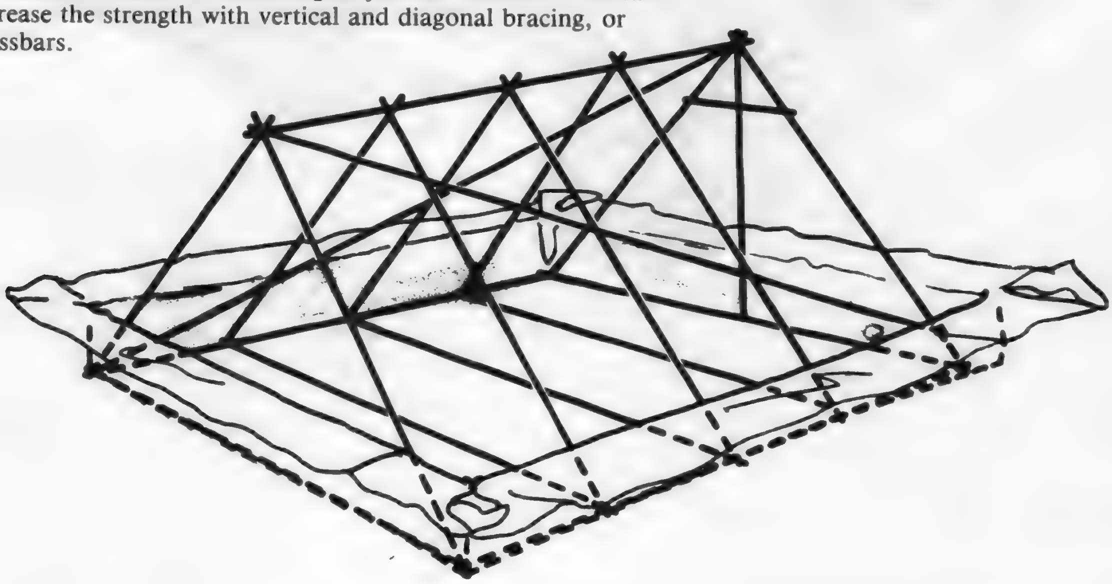


Fig. 57
Add the frame for the entrance tunnel, and also the ventilation pipe (described below).

Cover the entire frame (except the entrance hole) with plywood boarding. Any small gaps or sharp edges should be covered with carpet or thick fabric.

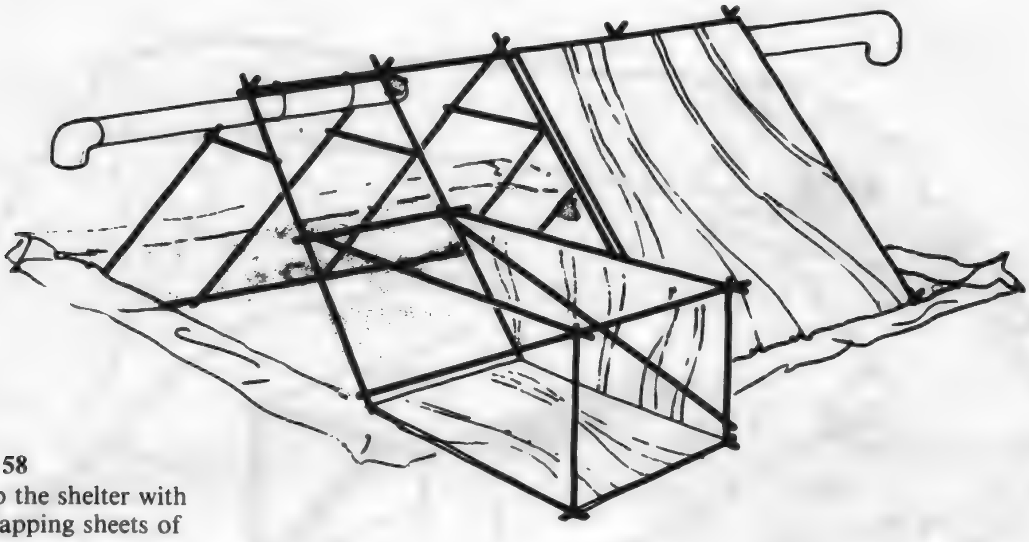


Fig. 58
Wrap the shelter with overlapping sheets of heavy duty polythene. Make sure the trench lining is tucked inside this cover to stop water running into the shelter space.

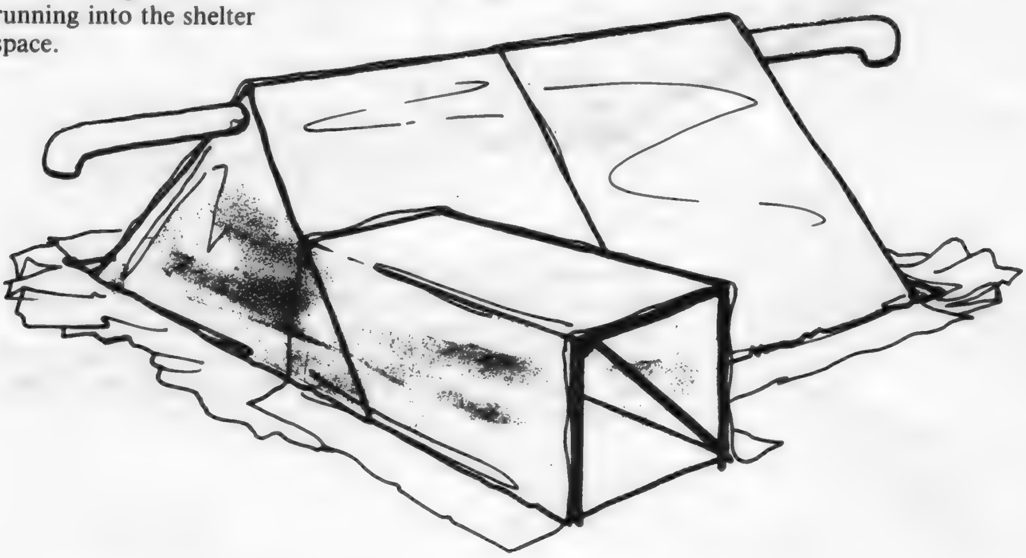


Fig. 59

For this shelter you will need to make some provision for ventilation. The diagrams show metal drainpipes with a bend near the opening, so that this faces downward. The opening should then be filled with a filter of steel wool. It is extremely important to ensure that ventilation pipes are secure and kept free of obstruction.

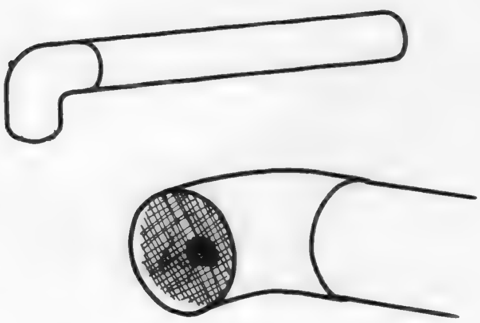
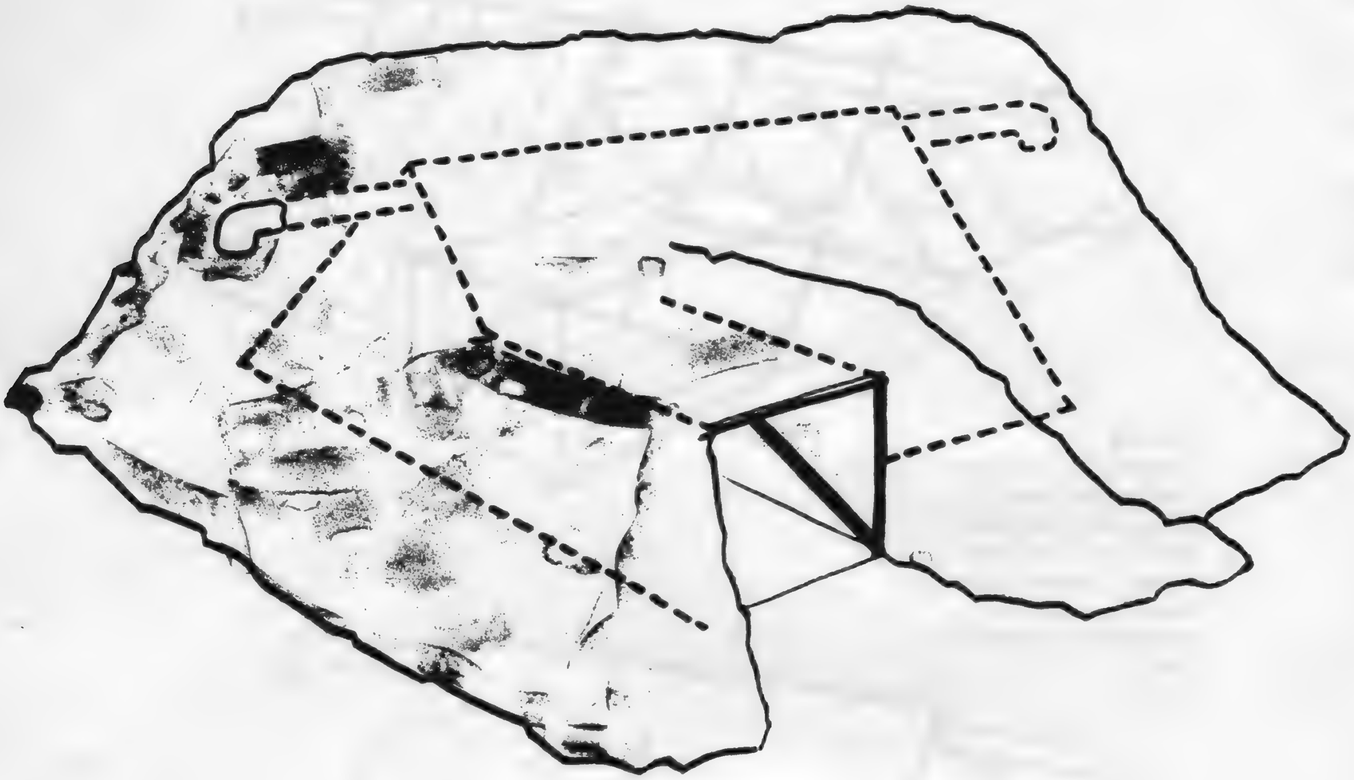


Fig. 60
Finally, cover the shelter with a thick layer of earth (about 450mm). The earth removed from the trench may not be enough for this. If you decide to dig a deeper initial trench to get enough earth to cover, you may have to make some modifications to the design given here.



The shelter will give better blast protection if you put a layer of resilient material between the polythene and the earth covering. Straw, mattresses, or similar, would be suitable. The entrance can be filled from within with small bags of sand or earth. You will have to store these inside the shelter.

Chapter 5
Indoor kit shelter design

General 5.1

This chapter gives information about an indoor shelter suitable for erection in homes that have basements or rooms that can be converted into a fallout room. It can be used as the 'inner refuge' referred to in the Home Office booklet *Protect and Survive* and anybody considering purchasing or using such a shelter should read *Protect and Survive* and be totally familiar with its contents.

The shelter will accommodate two adults and two small children. Two or more shelters can be placed together to gain more shelter area.

It should be stored in a clean dry place, ready for erection if required, *and could be used for other purposes, e.g. a workbench in a garage or garden shed.*

Shelter details 5.2

The indoor kit-type shelter is shown in Fig. 64.

A specialist steelwork fabricator will need to cut, weld, paint and drill bolt holes for the steel parts. However, once the units have been manufactured the shelter can be erected by unskilled labour. (Two persons two hours each.) Steelwork shop fabrication drawings are given in section 5.11, a steelwork specification in 5.10 and a guide to putting up the shelter in 5.12.

The basic unit has been designed to be capable of sustaining the debris load resulting from the complete collapse of a typical two-storey house, and when surrounded with brickwork, sandbags or other protective materials it will provide good protection against fallout.

Location of shelter 5.3

Where the shelter can be used 5.3.1

In two-storey houses and the lower floors of blocks of flats of substantial reinforced concrete or steel-framed construction, in areas where the density of building is comparatively low.

Where the shelter should not be used 5.3.2

1. Houses that have more than two storeys.
2. On the upper floors of houses or any ground floor that has a basement directly below it.
3. Blocks of flats having load bearing brickwork, blockwork or precast concrete panel construction.
4. The top two floors of a block of flats.
5. Lightly clad buildings.

Location of shelter in fallout room 5.4

As explained in *Protect and Survive* the shelter should be placed within the fallout room. Choose the place furthest from the outside walls and from the roof, or the room which has the smallest amount of outside wall or openings. The entrance should be positioned facing a solid internal wall wherever possible (see Fig. 65). A gap of 600 mm should be left between the outside of the fallout protection around the shelter and the walls of the fallout room to facilitate emergency escape.

The shelter should be placed on the most solid base available. When the shelter is to be placed on a suspended ground floor, this floor may require strengthening by providing additional piers, walls or props to support the floor joists.

5.5 Protecting the shelter against fallout radiation

Fallout protection to the shelter can be obtained by surrounding it with dry-laid brickwork, blockwork, sandbags, or heavy furniture filled with sand, earth or books (see Figs. 66 and 67). Recommended thicknesses of shielding materials are given in the following table:

Fig. 61 ***Recommended thicknesses of shielding materials***

	Thicknesses		
	To sides		To top
	Sides facing external walls	Sides facing solid internal walls	
Brickwork	1½ bricks (343 mm)	1 brick (225 mm)	4 courses bricks (260 mm)
Dense blockwork	1½ blocks (330 mm)	1 block (225 mm)	3 courses blocks (300 mm)
Sandbags	350 mm	250 mm	300 mm

If bricks or blocks are used they should be dry-laid, but closely packed and bonded so as to stagger the joints as much as possible. Suggested bonding is shown in Fig. 68.

Fallout room
External windows and doors in the room containing the shelter should be blocked up with material of the same weight as the surrounding wall. A 600 mm by 600 mm dry-laid area should be left within the blocked-up area to provide an escape exit.

For shelters protected as described, protective factors are given in the following table:

Fig. 62 ***Approximate protective factor***

House type	Protective factors	
	House with all exterior windows blocked	House with exterior windows blocked plus shelter and bricks
Terraced: traditional	15	260
modern	11	140
Semi-detached: traditional	12	210
modern	9	130
Detached: traditional	10	180
modern	8	110

5.6 Provision of emergency escape tunnel

Materials

Use tables, doors and other items of heavy furniture to form an emergency escape tunnel. As for *ad hoc* shelters, other structural commodities might be utilised for building escape tunnels. Fig. 69 shows how scaffold poles could be used for the purpose.

Location of escape tunnel

The escape route should be planned so that it emerges near to an opening in an external wall. If external openings are blocked up, a weaker escape knock-out area (e.g. dry-laid bricks or blocks 600 mm by 600 mm) should be provided.

5.7 Tools and materials required

For construction

16 mm and 10 mm spanners (1 open, and 1 ring, of each).
Steel lever for lining up holes.
Work gloves.

For shelter

Recommended quantities of materials for fallout protection are given in the following table. (Figures in table for entrance shielding wall, but do not consider materials required for blocking up openings in external walls.)

Fig. 63 *Amounts of material for protection*

Distribution of material	No. of bricks	No. of blocks	Soil/earth for sandbags
1½-brick equivalent on 4 sides of shelter and 5 courses on top	3300	550	5.2 cu m
1 short side of shelter shielded with 1½-brick equivalent, other 3 sides 1-brick equivalent, and 5 courses on top	2500*	420	4 cu m

*It takes four people approximately 10 hours to carry 2500 bricks from a stockpile and stack them around a shelter.

Shelter ventilation 5.8

The shelter entrance must remain open at all times to provide adequate free air passage into the shelter. If external openings have been blocked up in the room containing the shelter it is important that the door of the room should also be kept open.

Fitting out shelter 5.9

The shelter should be fitted out as described in Chapter 1 with the following additional items:

1. Heavy hand hammer
2. Crowbar
3. Masonry cold chisel
4. Wire cutters

Steelwork specification 5.10

1. Steel angle shall be metric angles to BS 4848, Part 4, 1972, or equivalent standard sections to BS 4, 1971.

2. The steel shall be grade 43 or 50 to BS 4360, 1969.

3. All fasteners are to be ISO metric black hexagon bolts and nuts to BS 4190, 1967.

4. All steel members shall be mechanically wire-brushed, then thoroughly cleaned with suitable detergent and rinsed with warm water to remove all corrosion products. When dry the element shall be primed with one coat of suitable metal primer and painted with one coat of compatible drying-oil undercoat and one coat of drying-oil finish coat all in accordance with the manufacturer's instructions.

Fabrication drawings 5.11

See Figs. 70–79

Fig. 64 ***Indoor kit-type shelter***

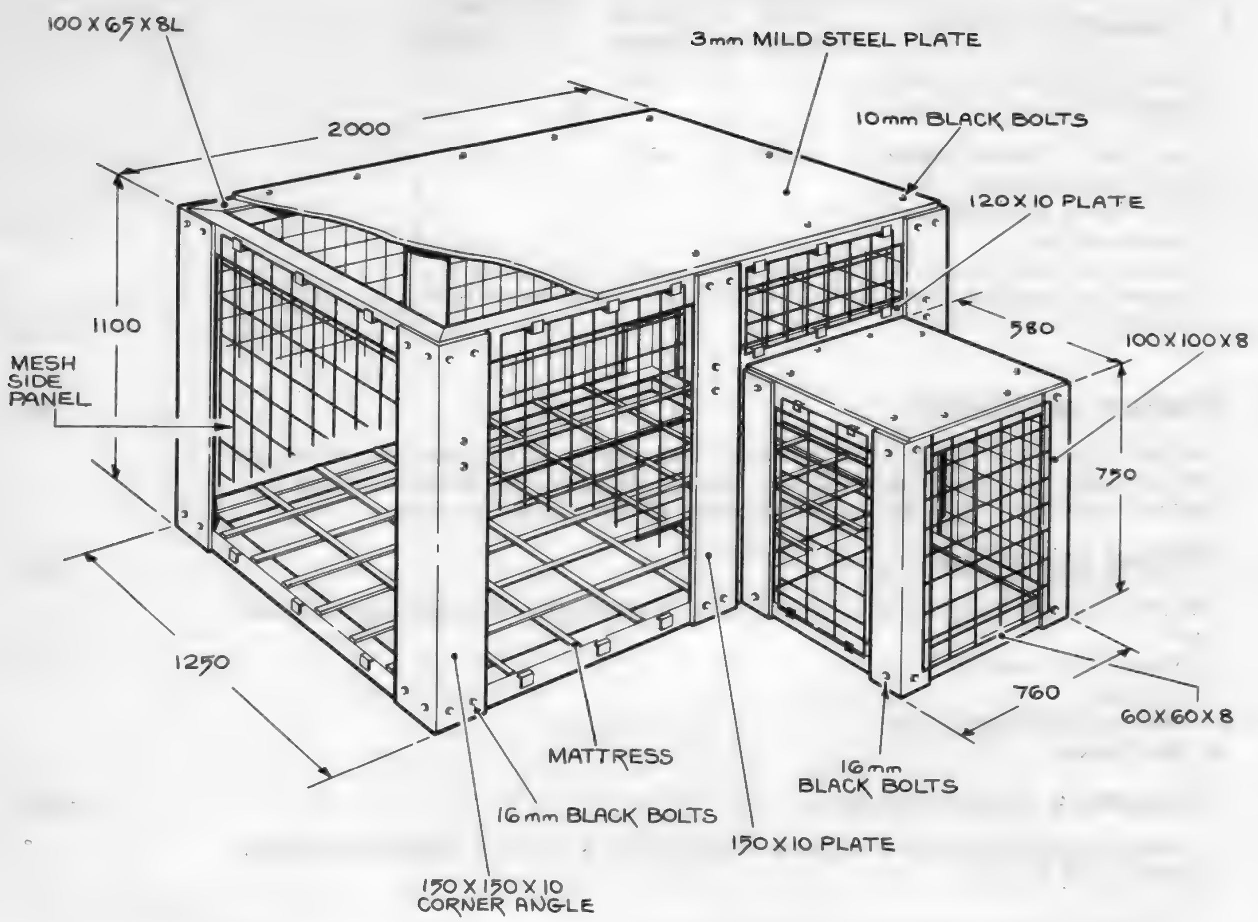
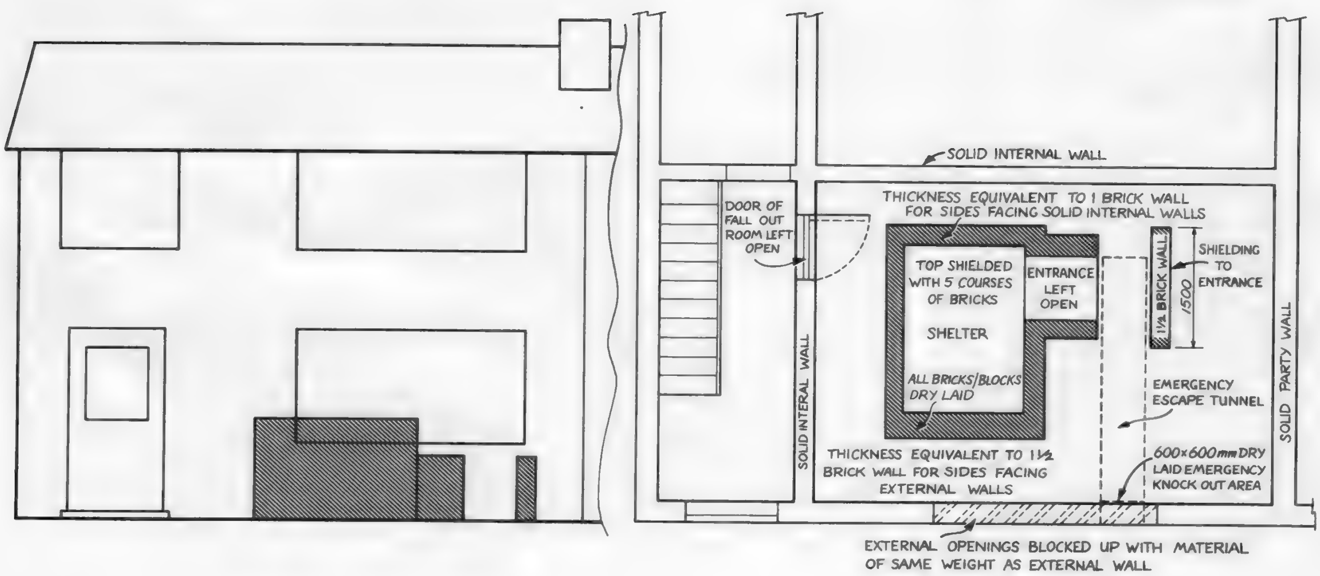


Fig. 65 ***Location of shelter***



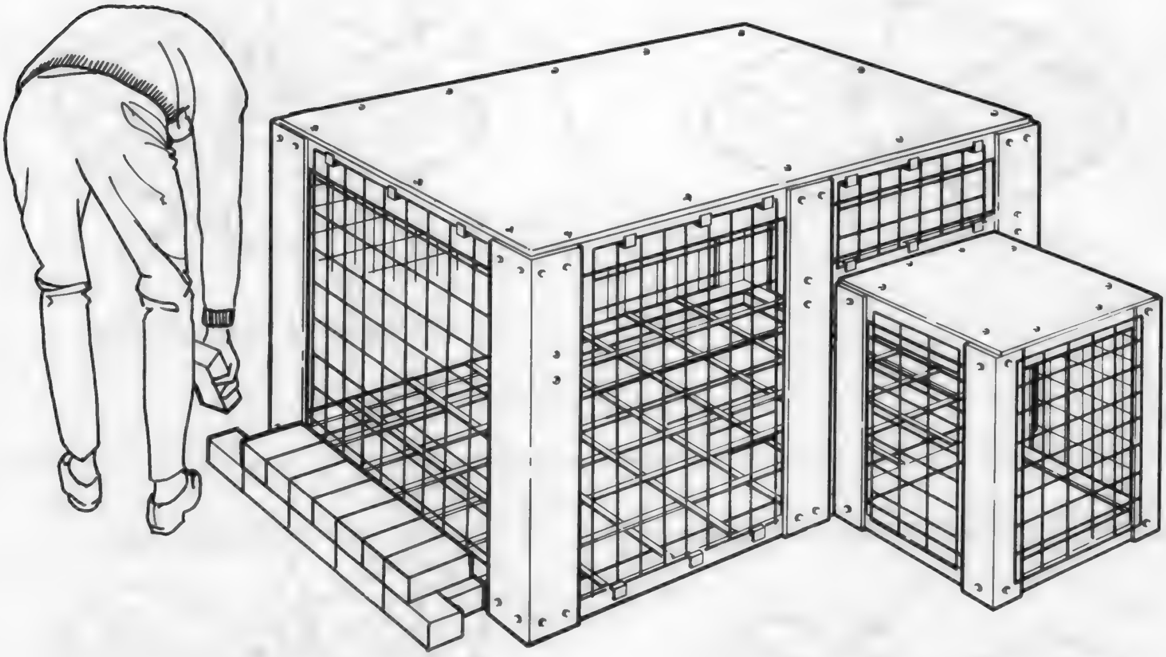
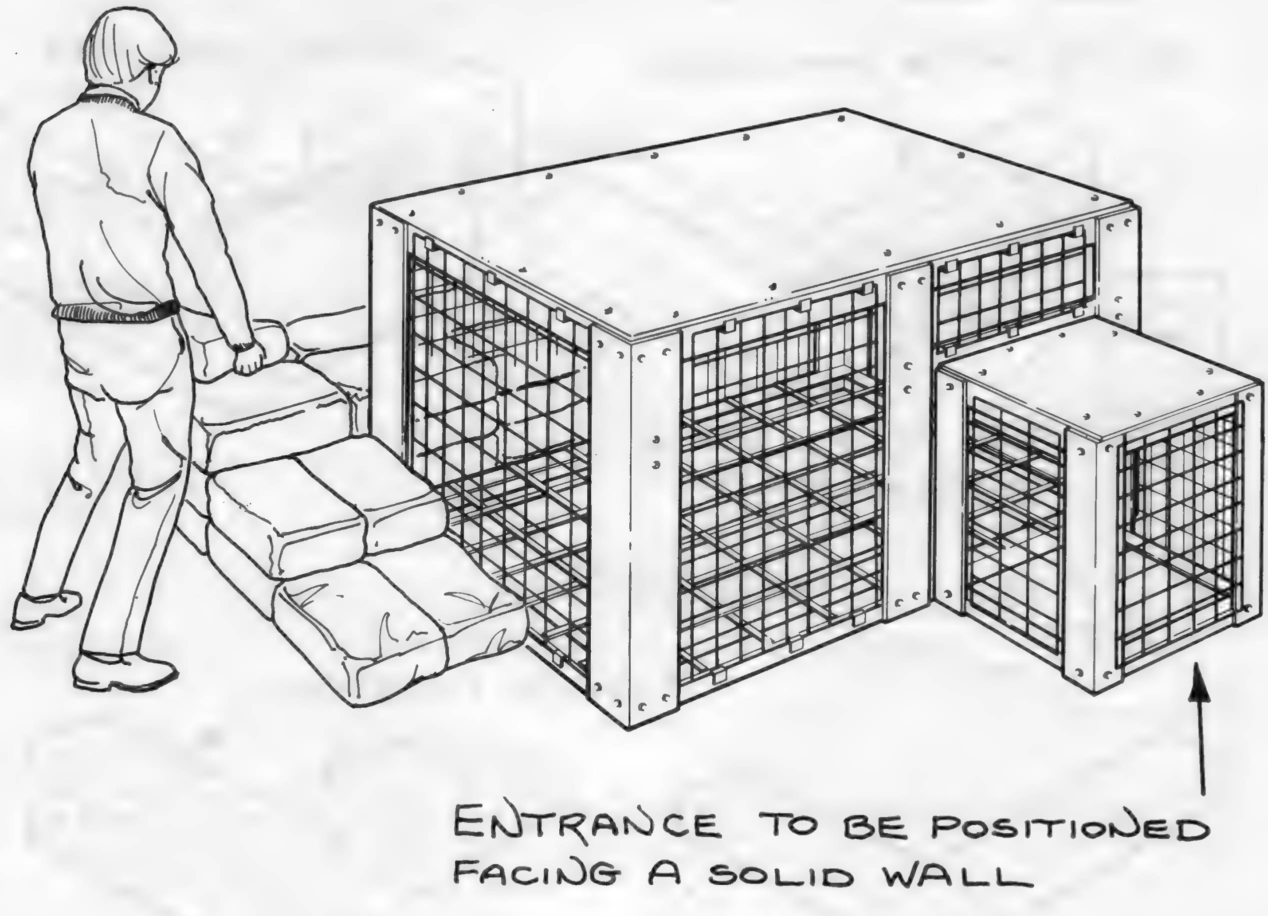


Fig. 66 *Shelter surrounded with bricks*

Fig. 67 *Shelter surrounded with sandbags*



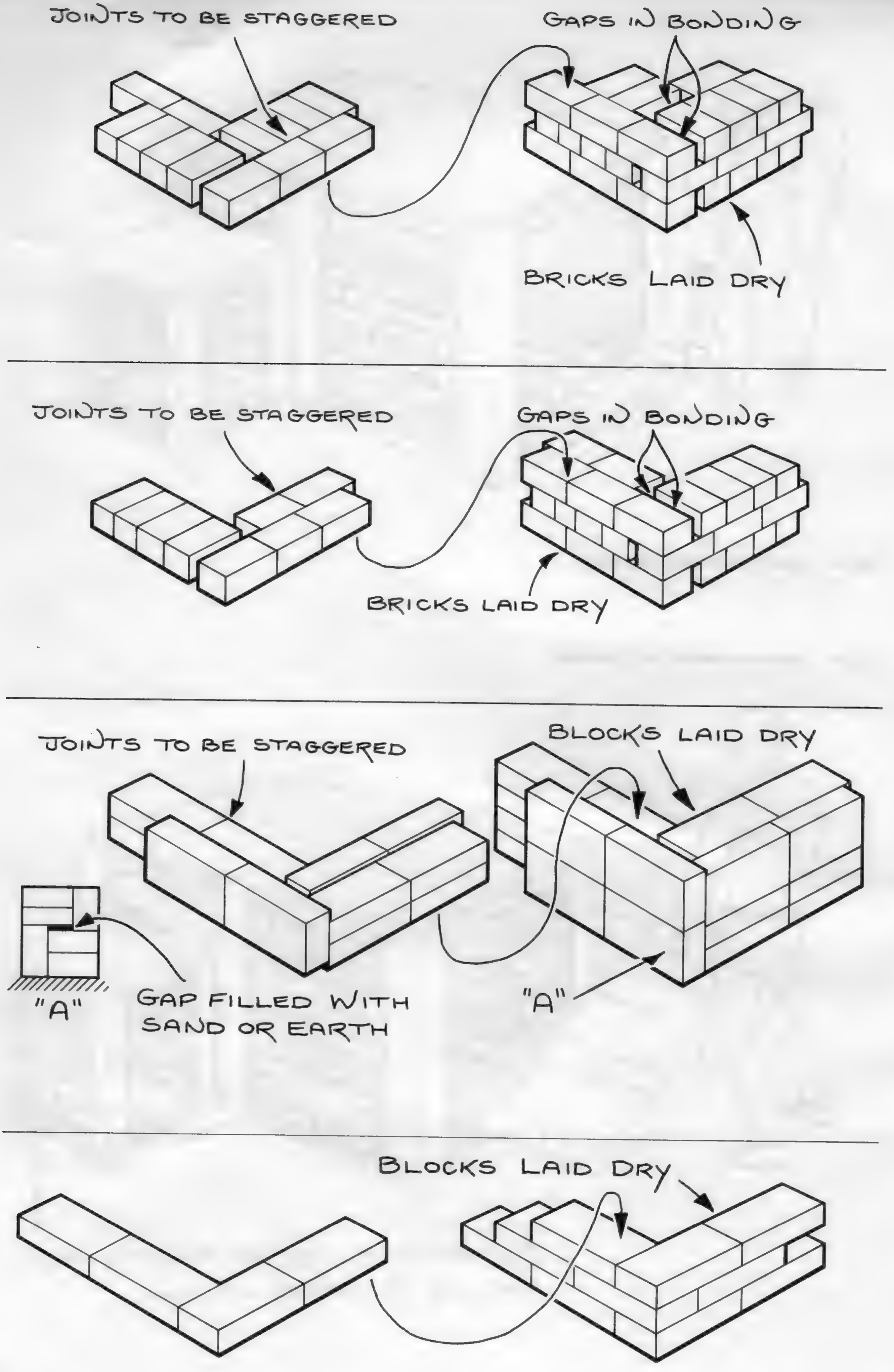


Fig. 68 ***Suggested bonding for brickwork and blockwork***

Fig. 69 *Emergency exit*

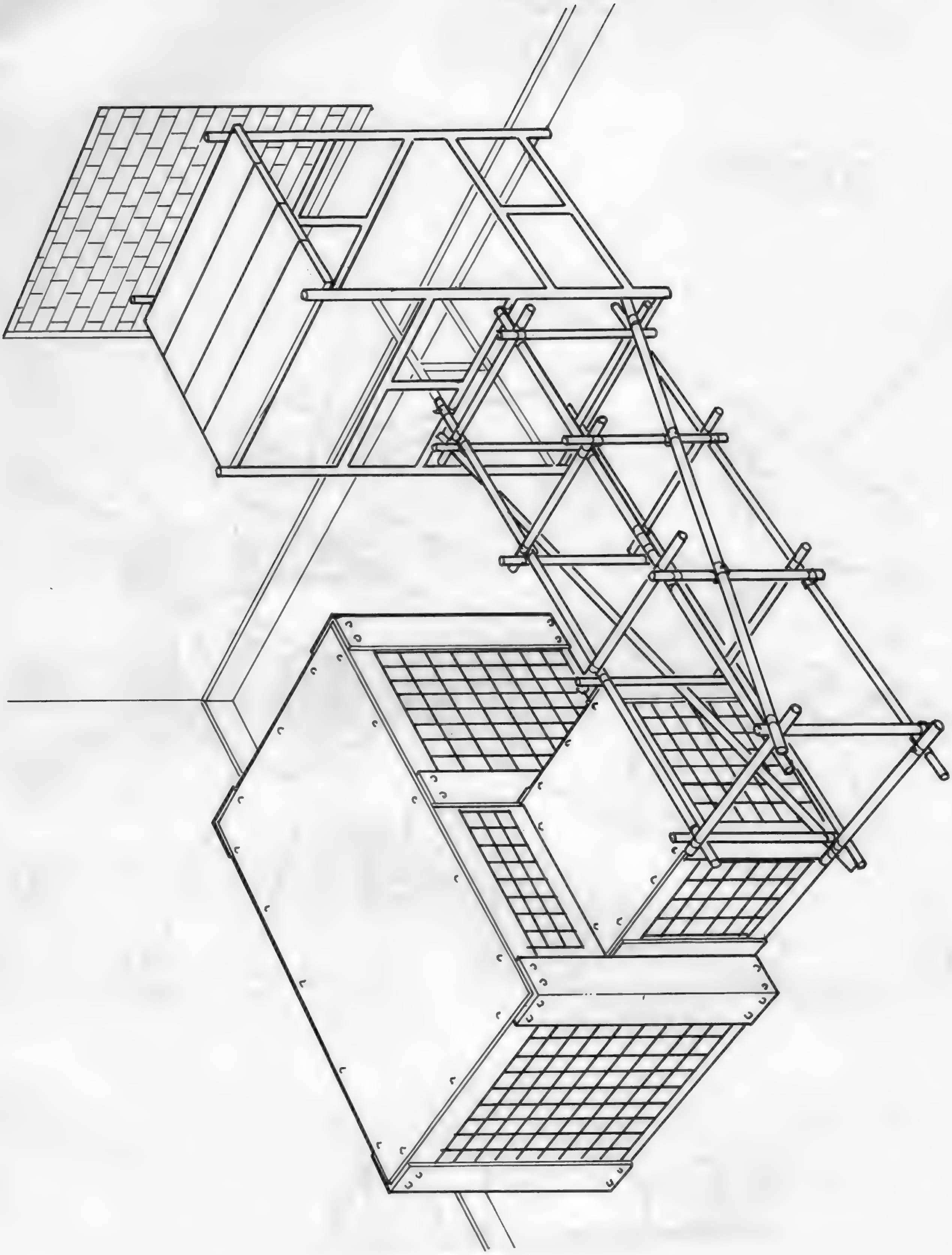
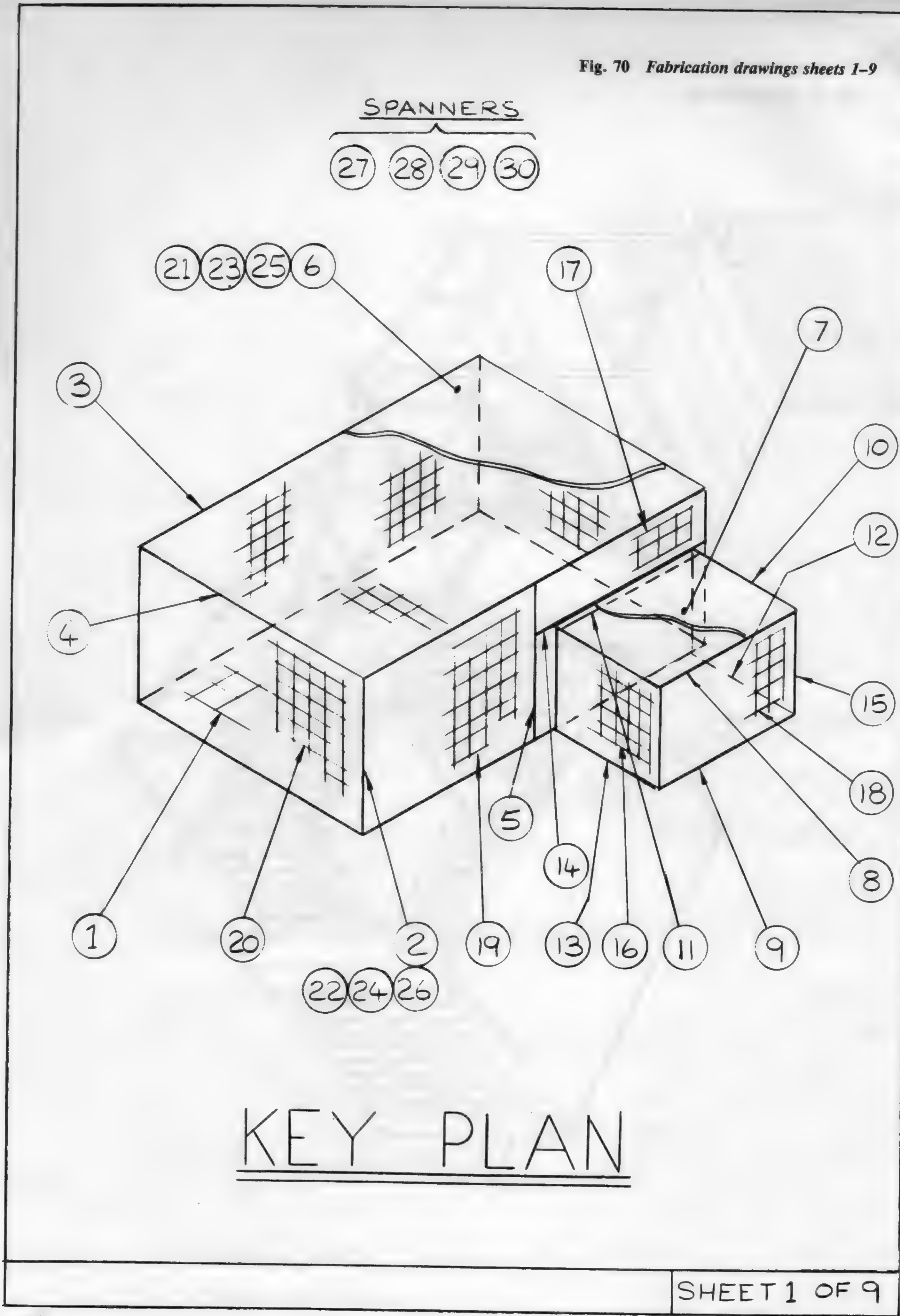


Fig. 70 *Fabrication drawings sheets 1–9*



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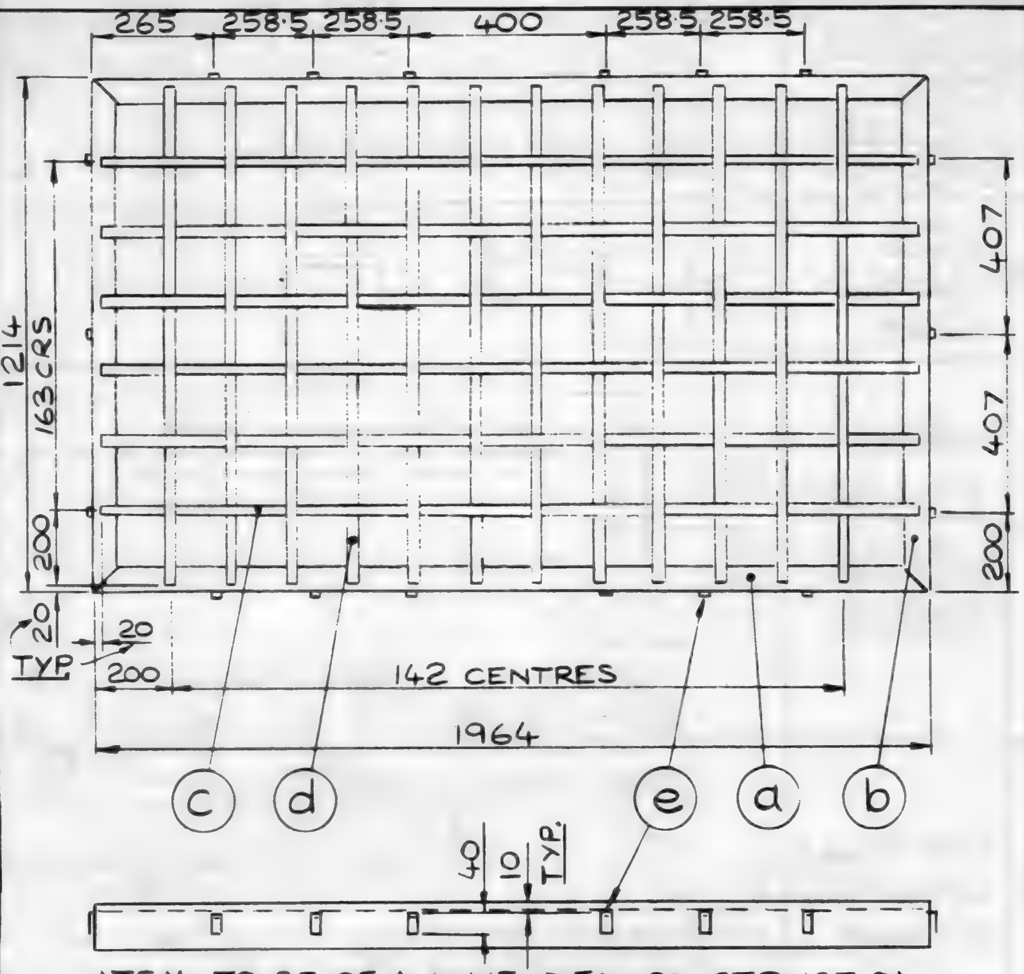
FOR ITEMS (a) → (e) SEE DETAILS 1(a) → 1(e)</td><td>

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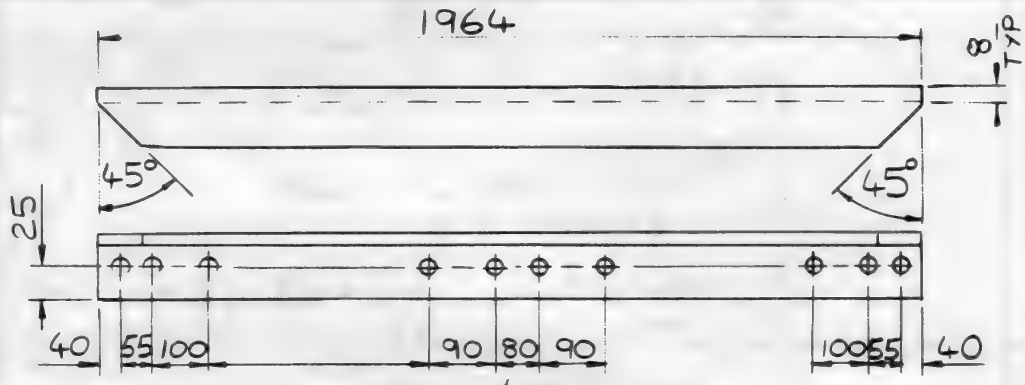
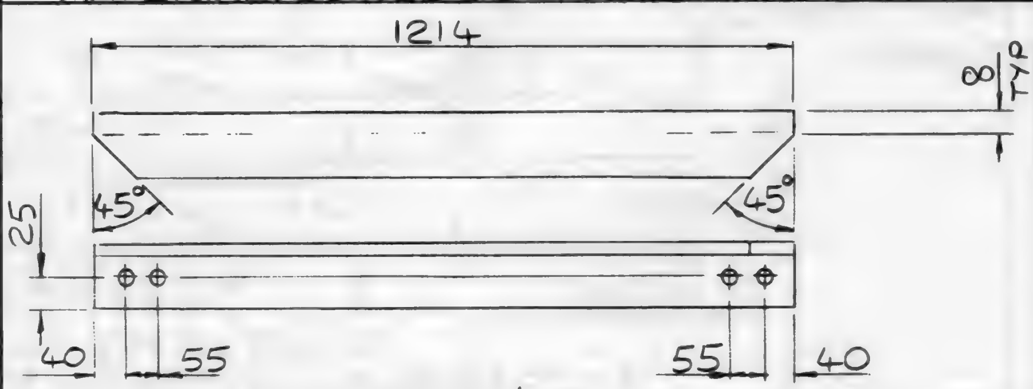
<tr><td>1(a)</td><td>BASE MATTRESS SIDE ANGLE (LONG)</td><td>

ALL HOLES Ø18
MATERIAL: 60 x 60 x 8 THK M.S. ANGLE</td><td>2</td></tr>
<tr><td>1(b)</td><td>BASE MATTRESS SIDE ANGLE (SHORT)</td><td>

ALL HOLES Ø 18
MATERIAL: 60 x 60 x 8 THK M.S. ANGLE.</td><td>2</td></tr>
</table>

Fig. 71

SHEET 2 OF 9

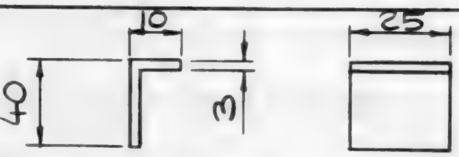
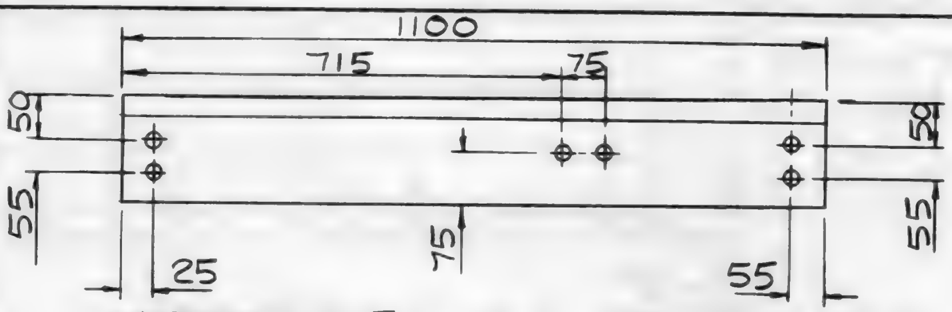
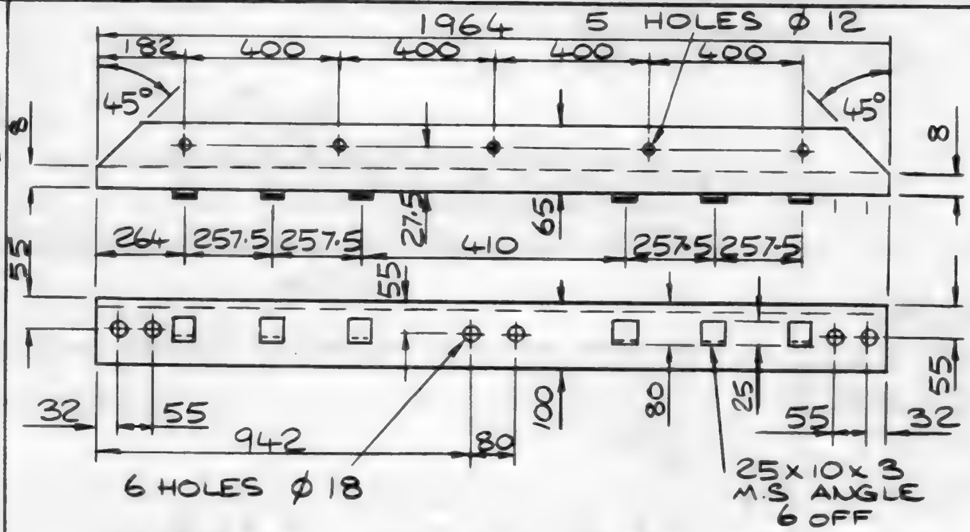
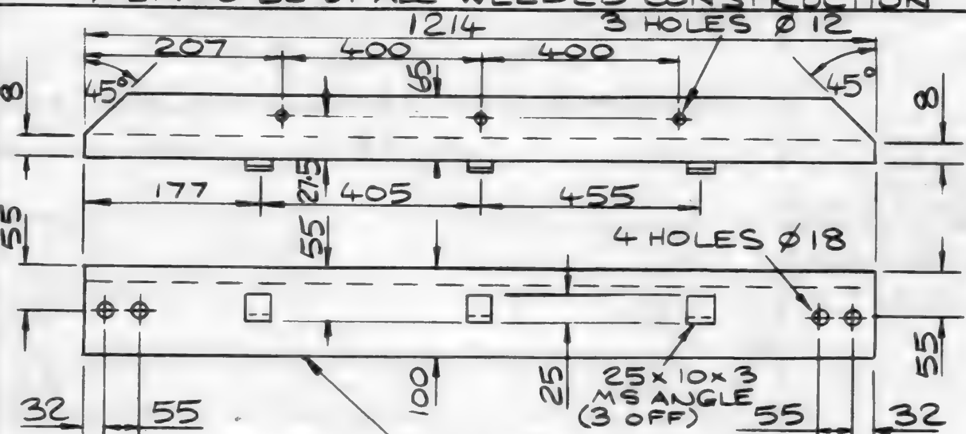
ITEM No	DESCRIPTION	DETAIL	No. OFF
1(c)	MATTRESS LATH (LONG)	25 x 2 M.S. STRIP 1960 LONG	6
1(d)	MATTRESS LATH (SHORT)	25 x 2 M.S. STRIP 1210 LONG	12
1(e)	SIDE PANEL HOOK		18
2.	MAIN FRAME CORNER ANGLE	 MATERIAL 150 x 150 x 10 M.S ANGLE ALL HOLES Ø18 BOTH WEBS TO BE DRILLED IDENTICALLY.	4
3.	TOP ANGLE LONG MAIN FRAME	 MATERIAL 100 x 65 x 8 TH'K M.S. ANGLE. ITEM TO BE OF ALL WELDED CONSTRUCTION	2
4.	TOP ANGLE (SHORT) MAIN FRAME	 100 x 65 x 8 TH'K MS ANGLE. ITEM TO BE OF ALL WELDED CONSTRUCTION.	2

Fig. 72

SHEET 3 OF 9

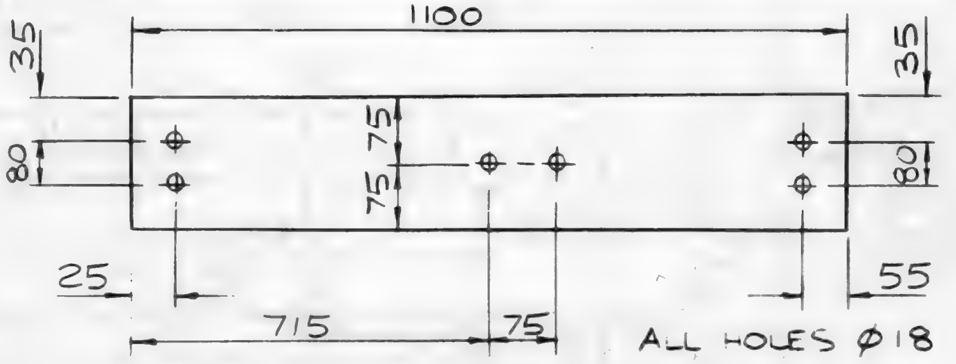
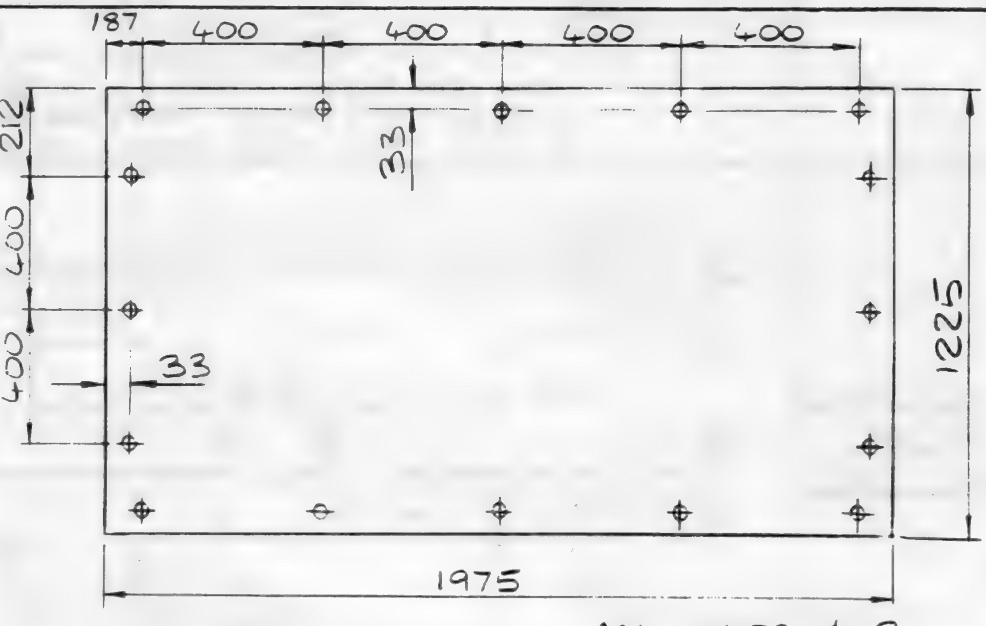
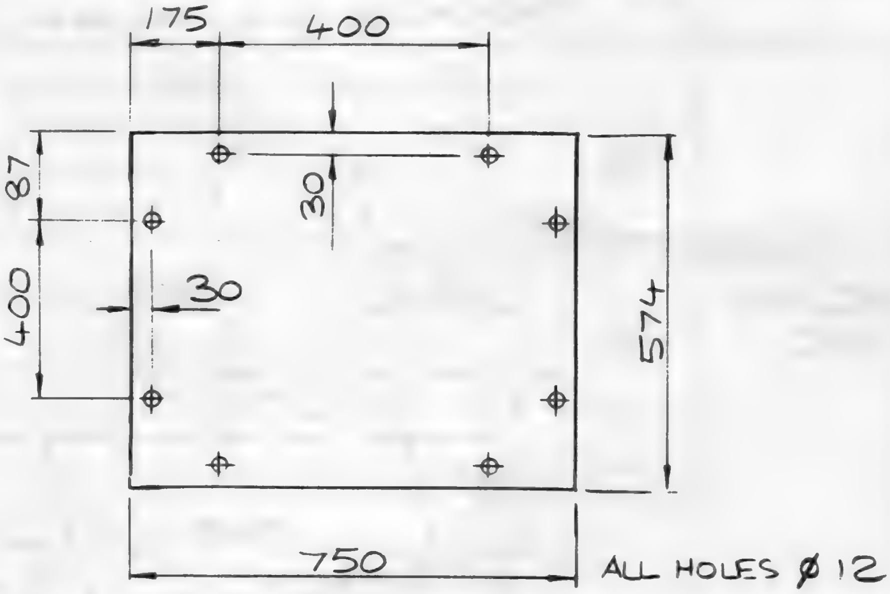
ITEM No	DESCRIPTION	DETAIL	No OFF
5	CENTRE PLATE	 MATERIAL 150 x 10 MS PLATE	2 2
6	ROOF MAIN	 MATERIAL 3 TH'K M.S. PLATE	1
7	ROOF ENTRANCE	 MATERIAL 3 TH'K M.S. PLATE	1

Fig. 73

SHEET 4 OF 9

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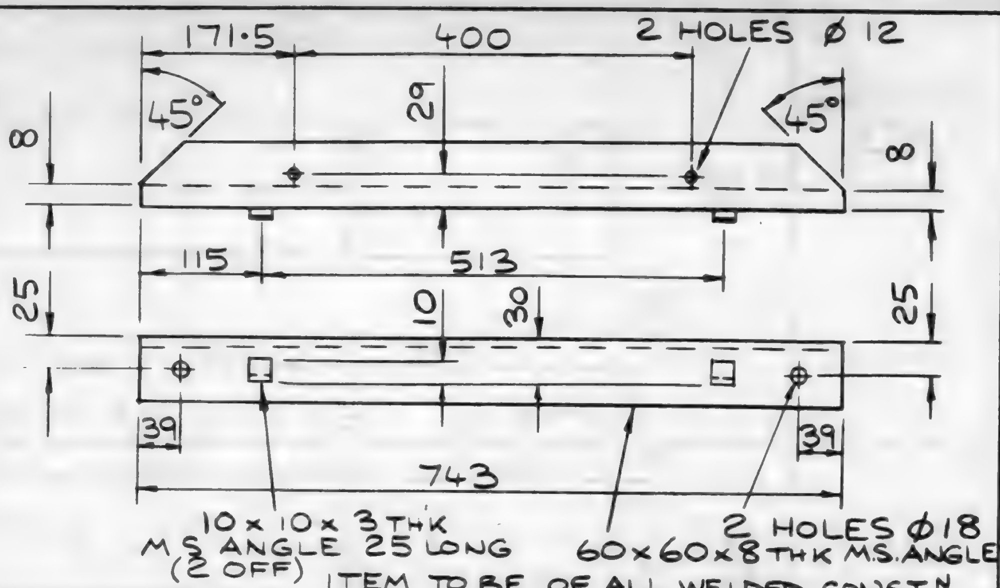

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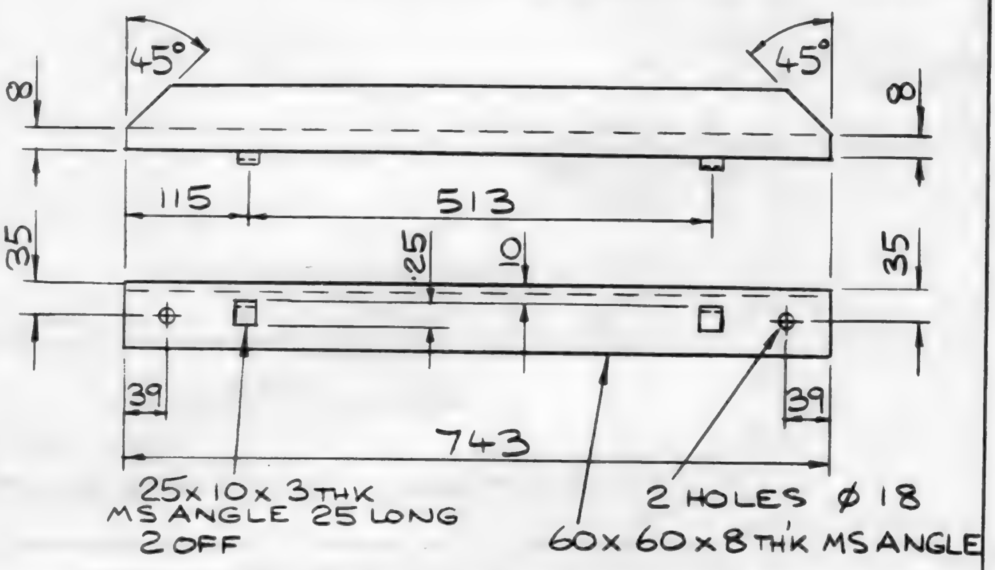

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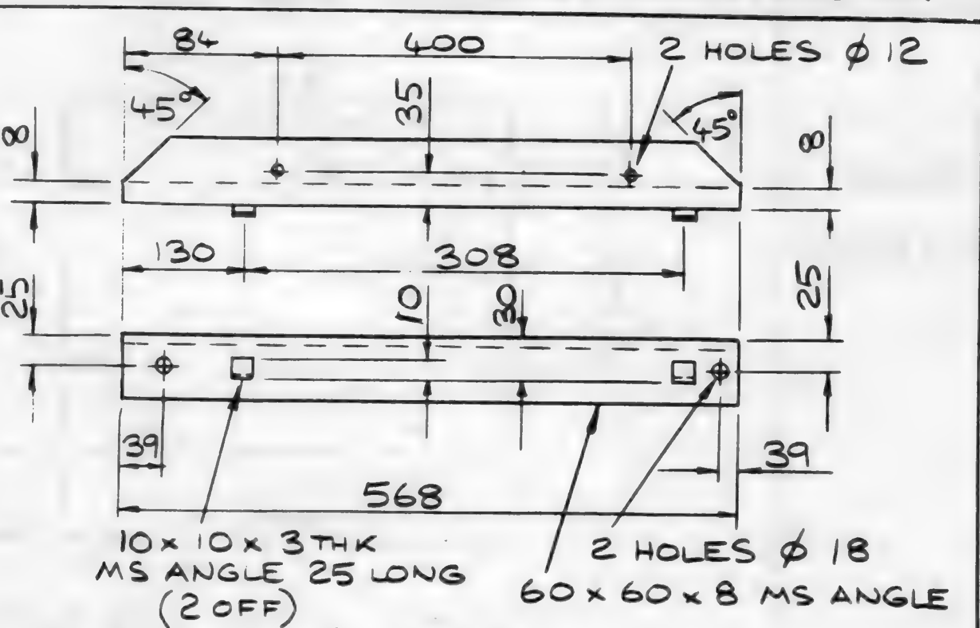

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Fig. 74

SHEET 5 OF 9

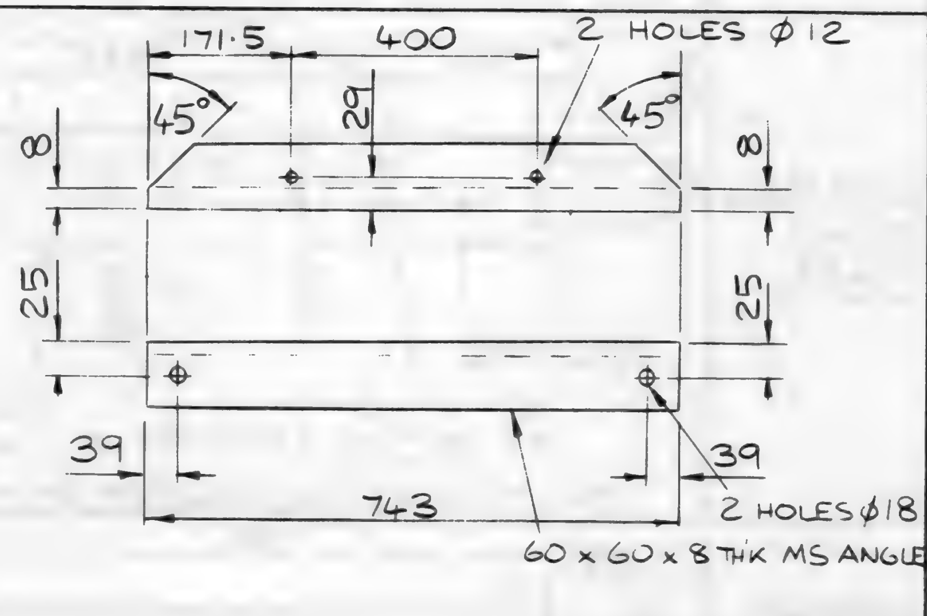
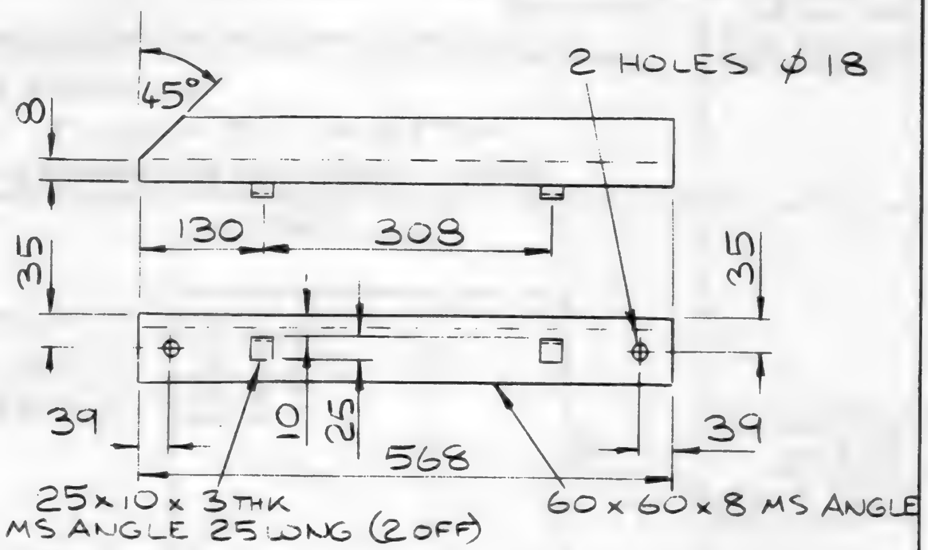
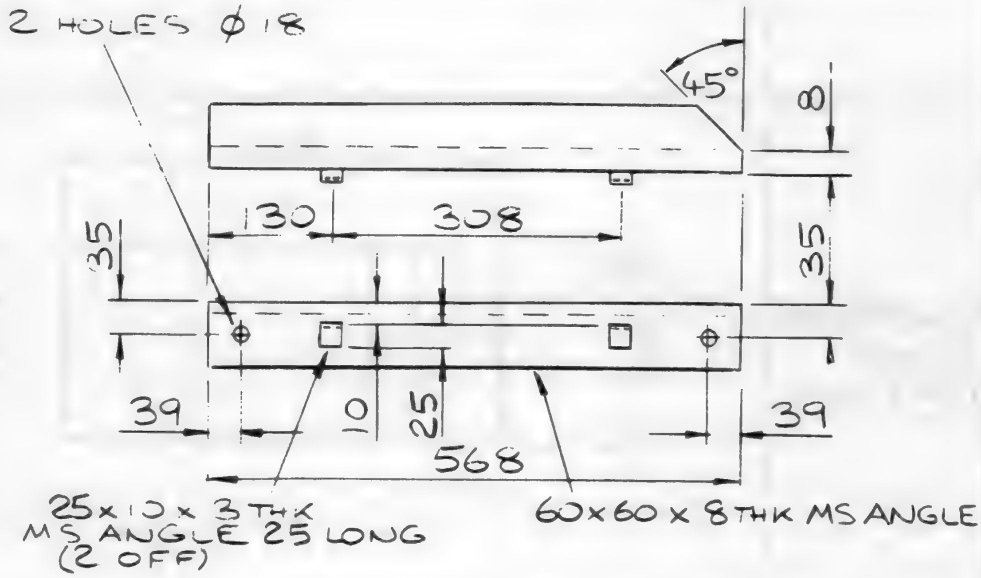
ITEM NO.	DESCRIPTION	DETAIL	No OFF
11	ENTRANCE TOP RAIL LONG BACK		1
12	ENTRANCE BOTTOM RAIL SHORT R/H	 ITEM TO BE OF ALL WELDED CONSTRUCTION	1
13	ENTRANCE BOTTOM RAIL SHORT L/H	 ITEM TO BE OF ALL WELDED CONSTRUCTION	1

Fig. 75

SHEET 6 OF 9

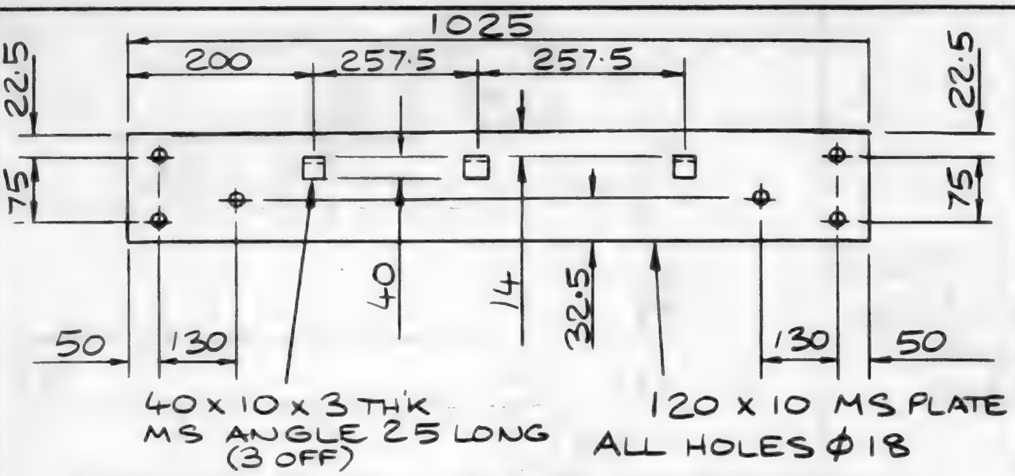
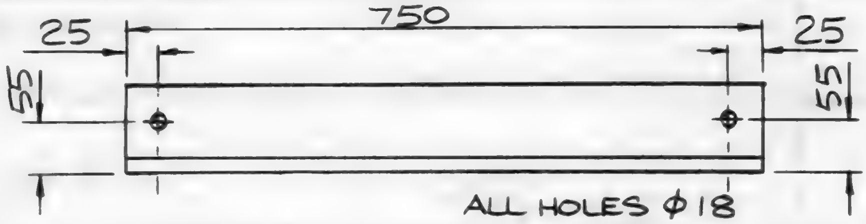
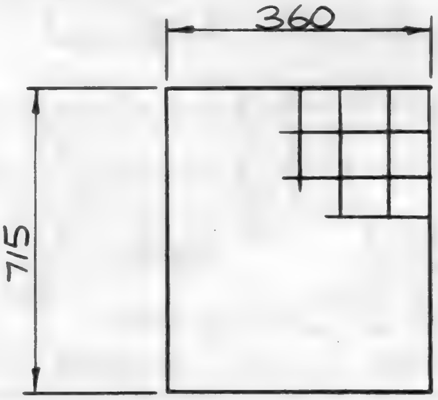
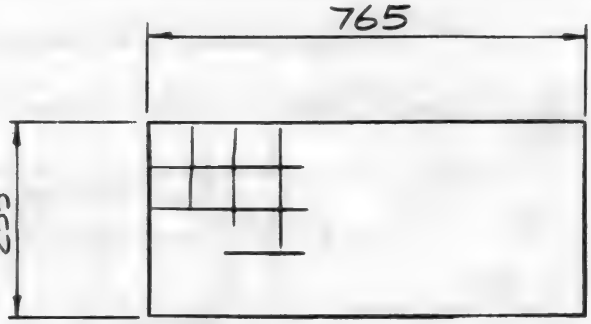
ITEM NO.	DESCRIPTION	DETAIL	No OFF
14	ENTRANCE FIXING PLATE	 ITEM TO BE OF ALL WELDED CONSTRUCTION.	1
15	CORNER SUPPORT ENTRANCE	 MATERIAL: 100 x 100 x 8 MS ANGLE BOTH WEBS TO BE DRILLED IDENTICALLY.	4
16	ENTRANCE FRAME SIDE PANEL	 MATERIAL M.S. MESH - 10 SWG WIRE ON 51(2") CRS	2
17	ENTRANCE FRAME TOP PANEL	 MATERIAL MS MESH - 10 SWG WIRE ON 51(2") CRS.	1

Fig. 76

SHEET 7 OF 9

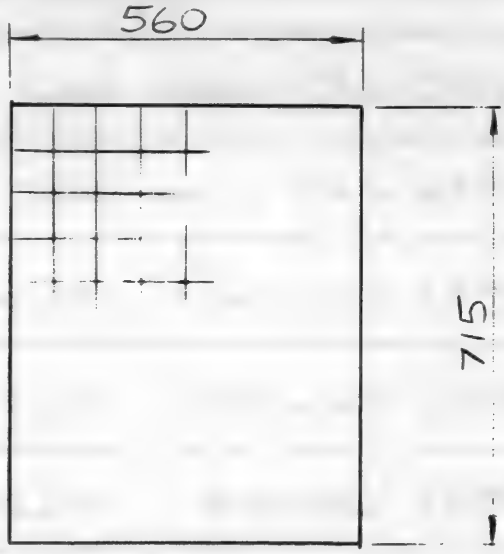
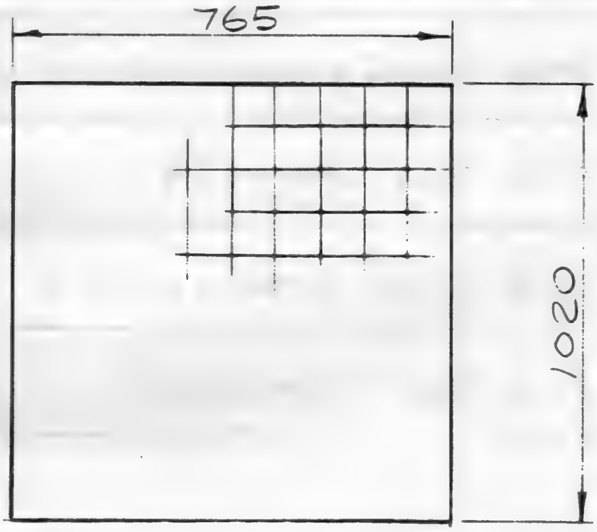
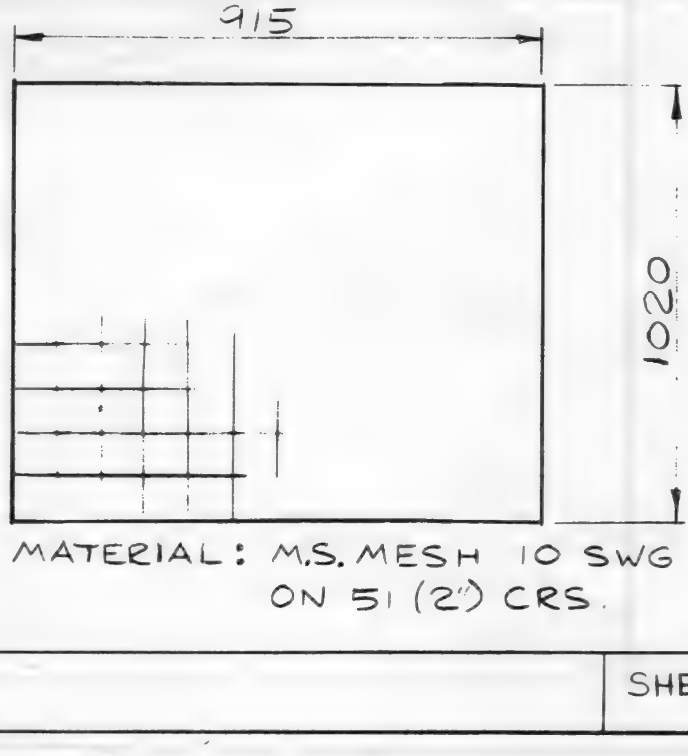
ITEM No	DESCRIPTION	DETAIL		No. OFF
18	ENTRANCE FRAME DOOR PANEL		MATERIAL: M.S. MESH 10 SWG WIRE ON 51 (2") CRS	1
19	MAIN FRAME SIDE PANEL SHORT		MATERIAL: M.S. MESH 10 SWG WIRE ON 51 (2") CRS	3
20	MAIN FRAME SIDE PANEL LONG	 MATERIAL: M.S. MESH 10 SWG WIRE ON 51 (2") CRS.		2

Fig. 77

SHEET 8 OF 9

ITEM No	DESCRIPTION	DETAIL	No. OFF
21	FIXING BOLT ROOFING	M10 x 21 LONG BOLT MILD STEEL	24
22	FIXING BOLT STEELWORK	M16 x 40 LONG BOLT MILD STEEL	60
23	FIXING NUT ROOFING	M10 FULL NUT MILD STEEL	24
24	FIXING NUT STEELWORK	M16 FULL NUT MILD STEEL	60
25	WASHER	M10 WASHER MILD STEEL	48
26	WASHER	M16 WASHER MILD STEEL	120
27	M10 SPANNER (SPIKE)	M10 OPEN ENDED x HOLE LOCATING SPIKE	1
28	M10 SPANNER (BOX)	M10 BOX SPANNER	1
29	M16 SPANNER (SPIKE)	M16 OPEN ENDED x HOLE LOCATING SPIKE	1
30	M16 SPANNER (BOX)	M16 BOX SPANNER	1

Fig. 78

SHEET 9 OF 9

Erecting the shelter

Stage 1

Study the list of parts and tools. Make a rough plan showing where the shelter is to be placed. Erection should not begin until some thought has been given to a suitable location as, once constructed, the shelter will be too heavy to move.

Stage 2

Having positioned base (item 1 in section 5.12), with mattress strips uppermost, fix one of the heavy angle legs (item 2) to each corner with large bolts. Note: holes in angle must be in line with those in base. (Fig. 79)

Stage 3

Hold the top rails in position, one at a time, and bolt them to the legs with the remaining 16 large bolts (putting the heads of the bolts outside and the nuts inside) the legs. Do not tighten the bolts yet. (Fig. 80)

Stage 4

Bolt two heavy centre strips (item 5) in the centre of the long sides, again ensuring holes line up in both base and top angle as shown in Fig. 81. Then place roof plate on top (item 6), using lever provided to line up holes if necessary and locate smaller bolts. Fit with nuts and tighten.

Stage 5

The single shorter heavy strip (item 14) is to be bolted horizontally between corner angle and centre vertical strip where the entrance is to be located (lugs facing down). Note: the entrance can be positioned in any one of four positions, i.e. either end of each of the longer sides (see Fig. 82).
Bolt the two upright rear entrance angles (item 15) to base and entrance support strip (item 14) as shown in Fig. 82, along with rear top support angle (item 11).

Stage 6

Bolt entrance bottom rails (items 12 and 13) with lugs facing down (Fig. 83). Erect front corner supports for entrance (item 15 – Fig. 84).
Attach entrance top rails with short lugs outwards and open end facing upwards (item 10).
Then fit entrance top rail long (item 8) to complete the entrance framework.
Fit roof (item 7) over entrance and bolt in position.

Stage 7

Attach wire-mesh frame in position all round by locating on lower lugs first and then lifting up and over on to top lugs. (Fig. 85)
Retain entrance panel (item 18) and keep adjacent to entrance for fixing when occupying the shelter.

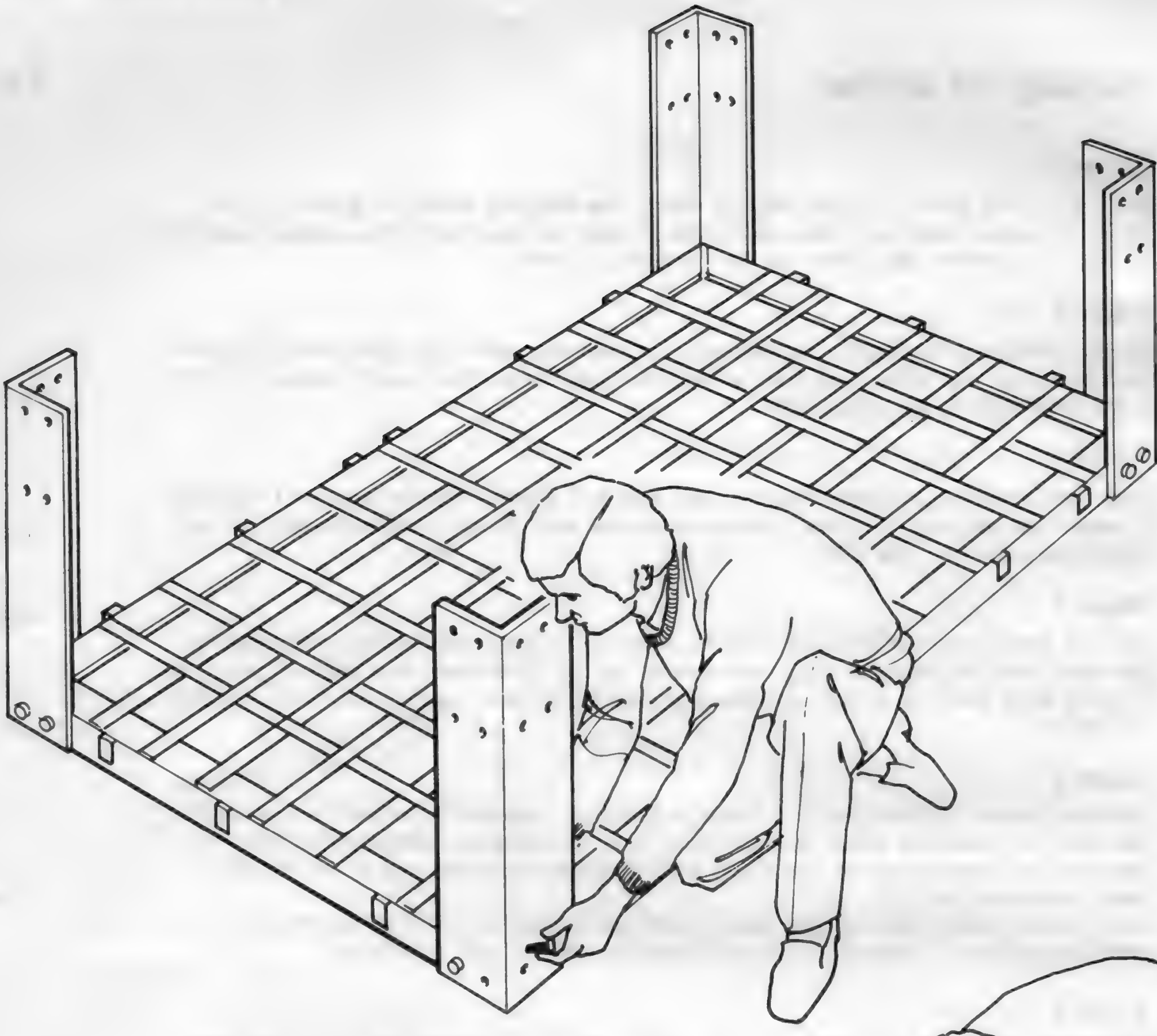
Stage 8

Erect fallout protection around the shelter.

Stage 9

Block up external windows and doors of 'fallout room' with material of the same weight as the walls of the room.

Fig. 79 *Erection drawings*



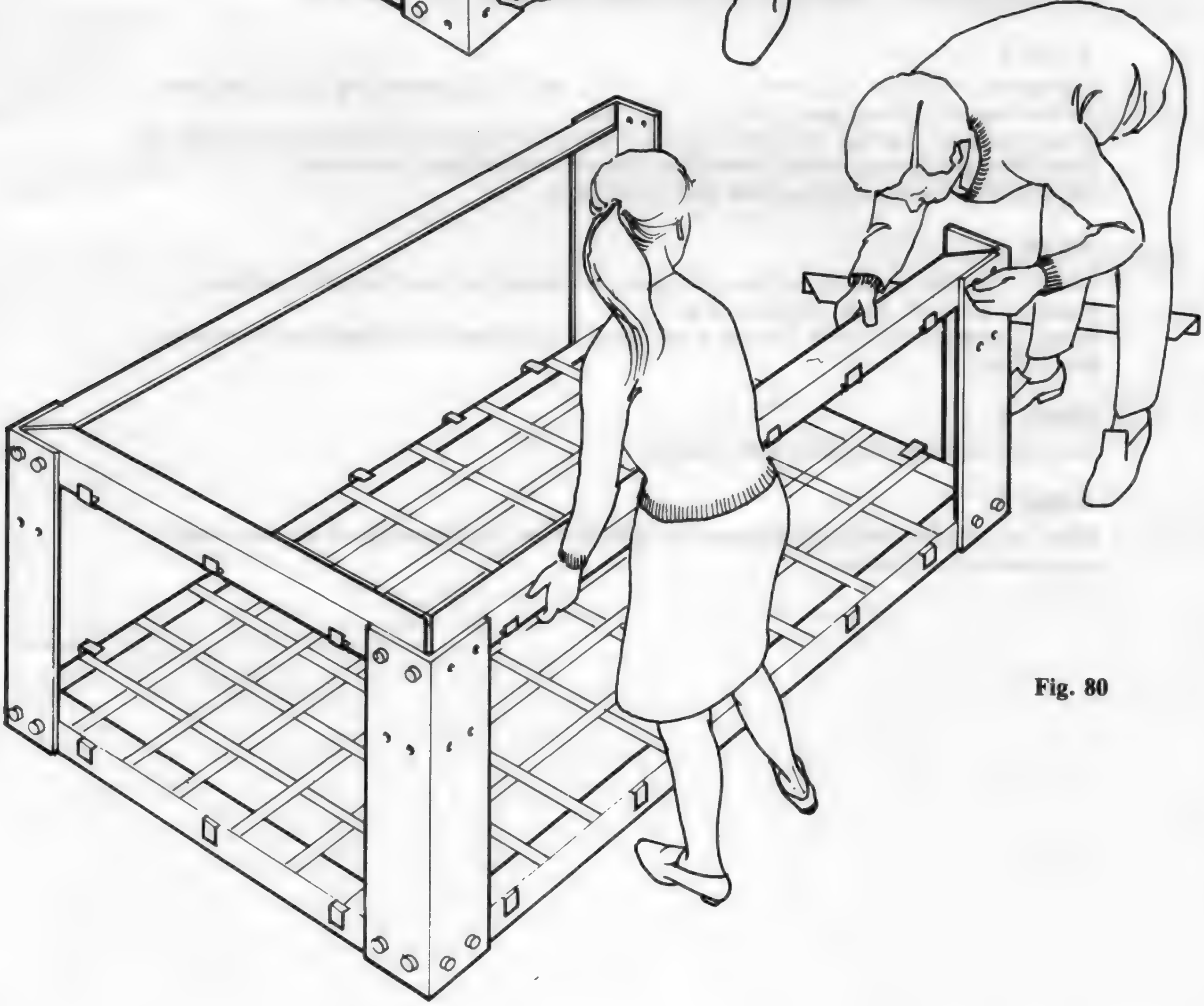


Fig. 80

Fig. 81

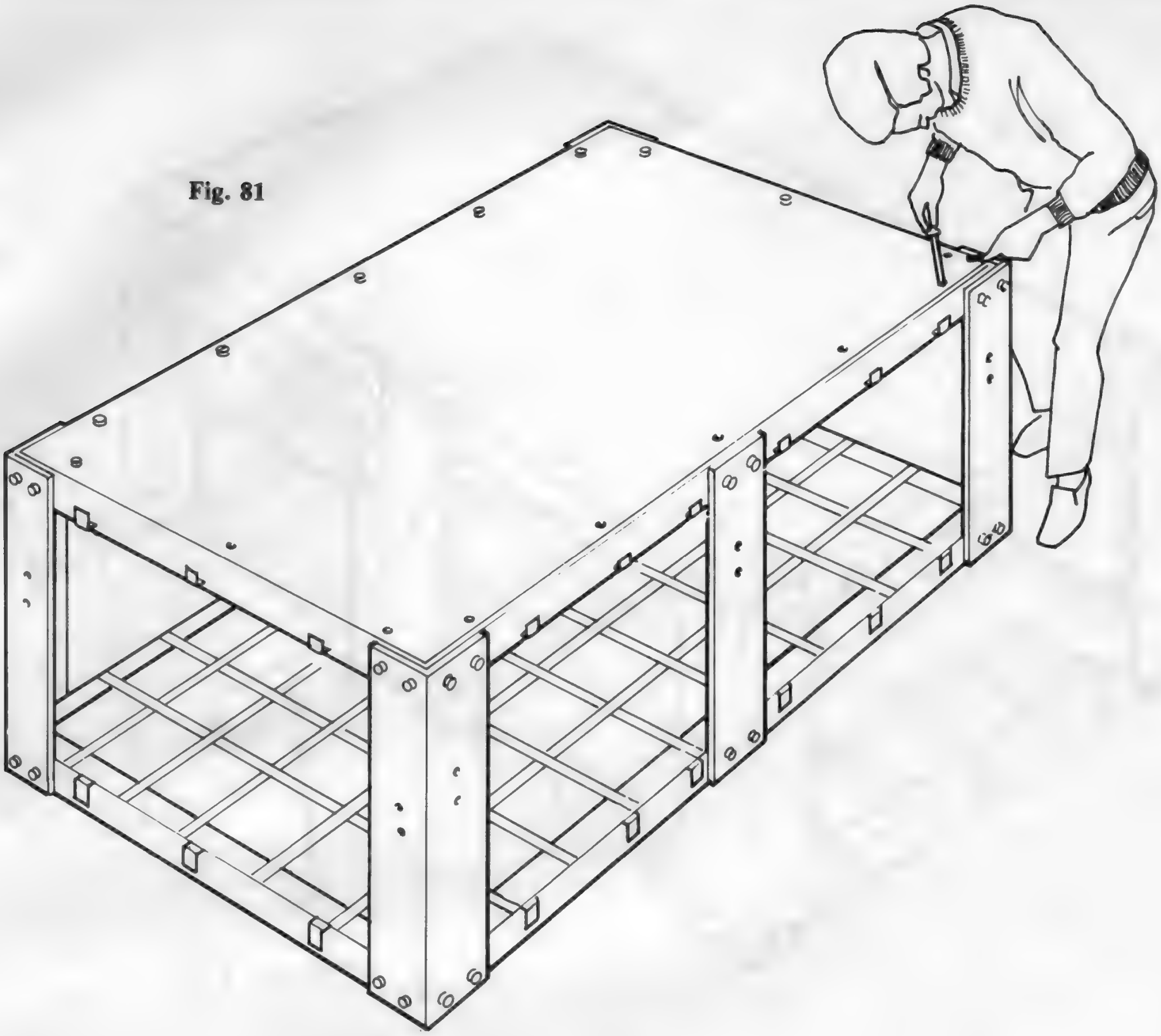


Fig. 82

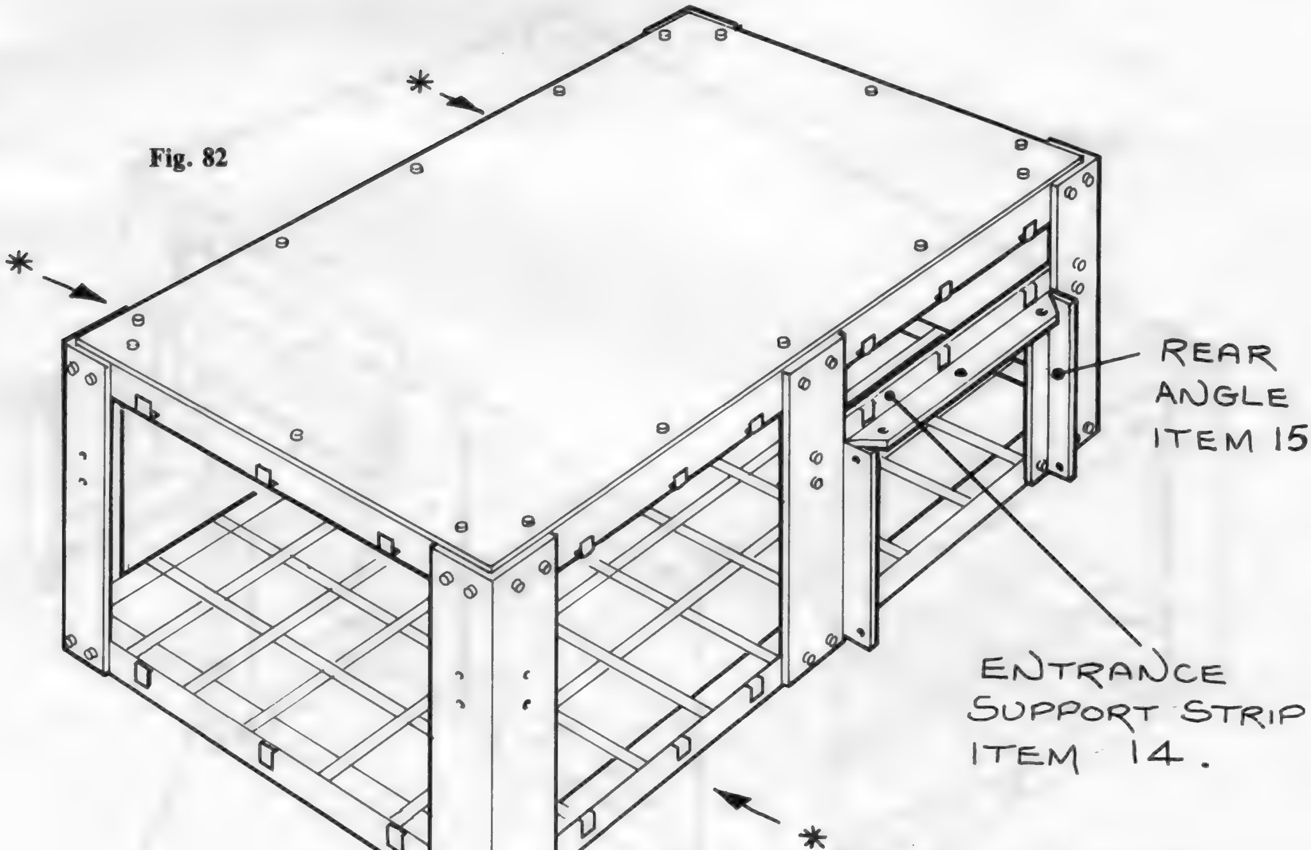

*
*
REAR
ANGLE
ITEM 15
ENTRANCE
SUPPORT STRIP
ITEM 14.
*
* ALTERNATIVE POSITIONS

Fig. 83

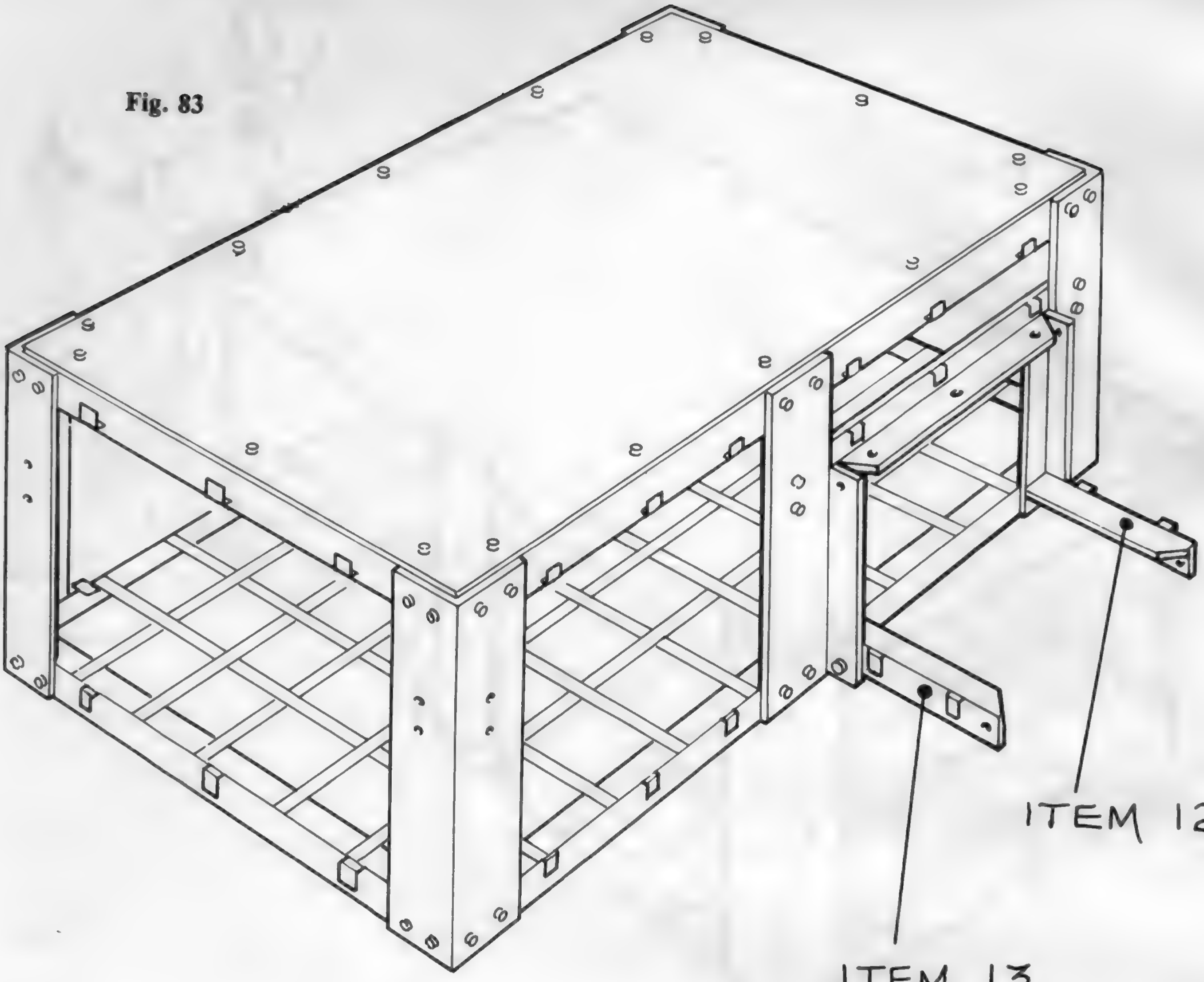


Fig. 84

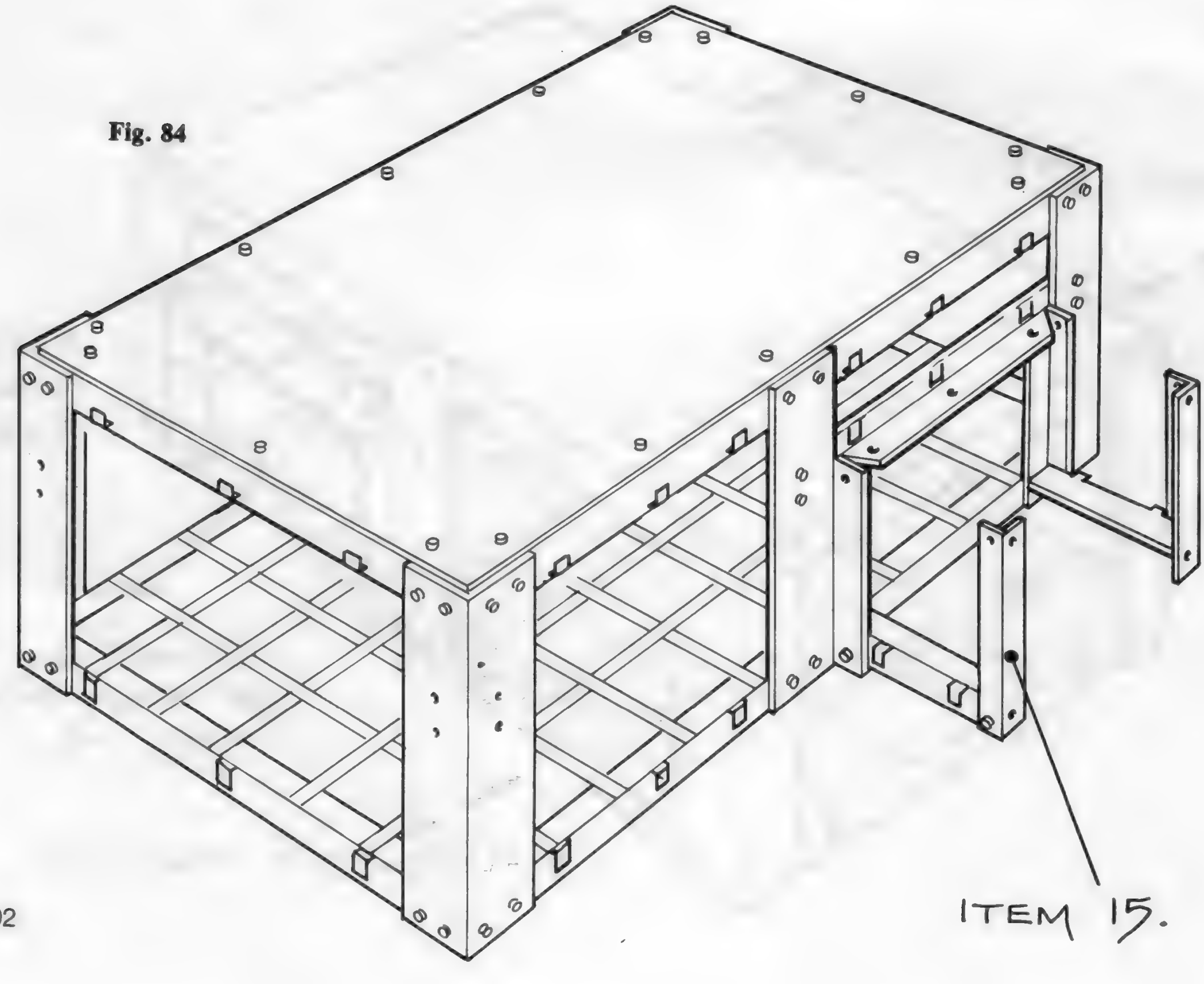
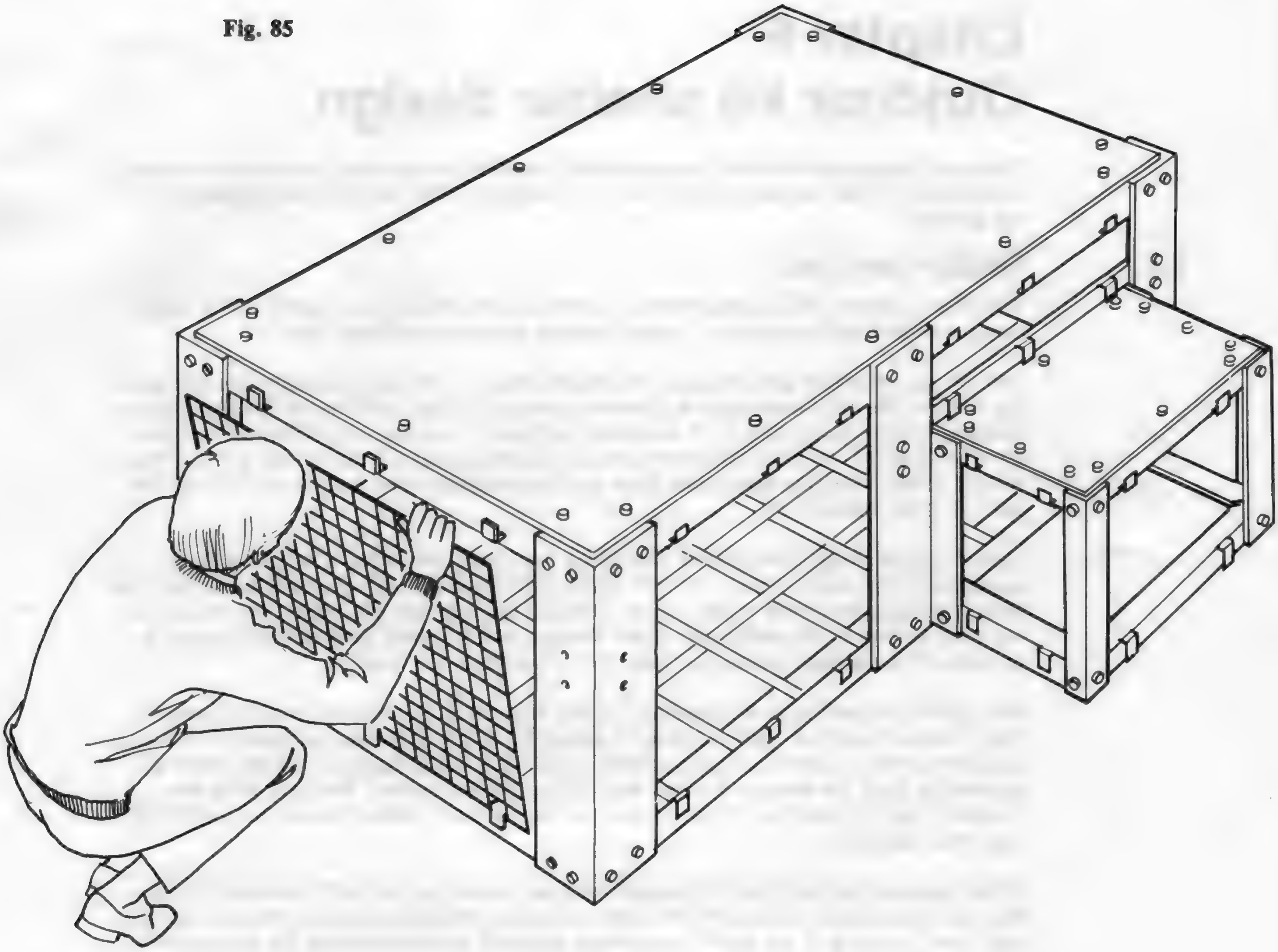


Fig. 85



Chapter 6
Outdoor kit shelter design

This is an earth-covered sealed structural shell capable of supporting a sufficient covering of earth to provide protection from blast and radiation. The shell is semi-submerged in the ground.

6.1 Design features

This size of shelter will accommodate four people comfortably (six cramped) in a single room, provided with ventilation, escape hatches, entryway and blast door.

The fallout protection depends upon the depth of earth covering which entirely surrounds the shelter. The blast protection is achieved primarily by the flexibility of the shell, which yields until the surrounding earth compacts sufficiently to deflect the blast wave around the shell. Earth compaction and earth arching around earth covered objects are important factors which come into play under blast loading conditions and protect the shell against damage from blast effects.

Under relatively high blast loading conditions the shelter will suffer some permanent damage and distortion of the roof and floor, with the roof being pushed downwards. This downward movement will result in more effective arching over the shelter and will reduce the blast stresses in the shell itself. Some movement downwards of the loaded shelter is desirable to promote protective arching over and around the structure.

One method of adding to the flexibility of the structure is to surround it with a layer of shock-resilient material such as straw, or expanded polystyrene sheet or granules. The layer should be about 150 mm deep and covered with a sheet of polythene or other sheeting material to limit the passage of earth dust during the blast phase. Some air from the crushable layer is liable to be blasted into the shelter itself during conditions of relatively high blast loading.

When surrounding the shelter with earth the sides should be very well-compacted; this must be done before placing the top cover. Measures should be taken to prevent excessive blast wind scouring of the earth cover above the shell, such as securing the surface with a stone mixture, rockery, concrete or paving cover.

A substantial ground level concrete slab cover extending beyond the plan area of the shelter would assist in reducing the blast effect on the shelter. A preferred scheme is shown on the drawings.

In some locations it may not be possible to entirely avoid the ingress of external ground water into the shelter. For cases where leakages occur electrically powered automatic pumps should be installed together with a stand-by hand operated pump. For cylindrical shaped shelters the space beneath the horizontal floor layer can be used as a sump. For flat bottomed shelters a slatted sub-floor should be used.

6.2 Construction of the basic shell

The shelter is based upon the Anderson shelter used during World War II, but it is sealed and designed to act together with the earth cover to protect the occupants against blast and radiation. Two shapes are indicated on the drawings, one is flat-bottomed, the other is cylindrical.

The shelter is made from strong prefabricated steel components bolted together and has the following constructional advantages:

a. It can be mass produced, with consequent cost benefits.
b. The components are reasonably compact.
c. The components are relatively light.
d. It can be transported easily.
e. The shelter could be made from either corrugated galvanised steel sheet, or from corrugated stainless steel.
f. The shelter could either be erected and installed by reasonably competent people on a do-it-yourself basis, or by a reputable contractor.

Constructional check list (to be read in conjunction with the drawings) 6.3

a. Select site, preferably sheltered by surrounding terrain.
b. Set out shape of excavation.
c. Excavate and place excavated material at least 300 mm from the edge of the excavation. The depth of the excavation is to be 1.3 metres below the original ground level.
d. Lay plywood base slabs horizontally on the ground to extend 25 mm beyond the peripheral edge of the shell and covered externally with Expandite Proofex No 12 or similar material with sufficient material to lap up all sides.
e. Connect the various components together ensuring that a continuous compressible sealing strip is inserted between the steel sheets at the joints. Start with the base, then the arched sides, and be sure to put all the components together and check for fit before tightening up the bolts.
f. Fit the doors.
g. Fit the escape hatches. There are two of these – one should be fitted from inside and one from outside.
h. Fit the ventilation pipes and equipment.
i. Apply continuous strips of Syl Glas joint sealant or similar material to all external joints throughout the shell.
j. Finally wrap the entire shelter with Expandite Proofex No 12 or similar, ensuring that generous laps are made with that extending up from the base slab and with adjacent pieces.
k. Backfill and well compact soil to the sides up to the original ground line.
l. Place 150 mm layer of crushable material around the crown and cover with a polythene or sheet layer.
m. Place earth above the shelter to ensure a minimum thickness of one metre everywhere.
n. Finally, protect the earth surface against effects of wind scouring by stabilising with grass of tough root variety, paving slabs or concrete layer.
o. Try to arrange for the entry area immediately in front of the entry point to be as small as possible so as to minimise the blast hazard.
p. Keep a reserve of sand or earth bags of convenient size in the entry tunnel to stack against the external door to provide the blast resistance, but take care not to block the air extract.

Buying a shelter 6.4

When considering the purchase of a shelter or any associated equipment i.e. ventilation pump etc., be sure to consult a reputable supplier or installing contractor who can vouch for the quality of all materials, preferably with manufacturers' certificates.

When considering choice of materials take proper account of your needs relative to the 'shelf' life of the materials if you intend to store them for installation at a later date.

Use materials that will withstand the rigours of the environment and will not corrode or lose strength for any reason.

Cost will undoubtedly be an important factor, but remember that you only get what you pay for. For example, a stainless steel shelter is likely to cost twice as much as a galvanised steel shelter but should serve reliably for an indefinite period.

If you choose galvanised steel check that there are no scrapes or other untreated parts *after* erection and *before* backfilling the earth. You might also consider the application of an epoxy type paint to ensure a longer life.

Additional comments 6.5

The shelter arrangement detailed in this chapter should prove to be a practical proposition for the majority of cases where a garden area or other convenient land nearby the living accommodation is available for the purpose. Being a semi-submerged arrangement then the excavation time is minimal in terms of obtaining the desired earth cover.

It is essential for the shelter to be constructed in peace-time in order to construct it properly. If however you install the shelter during the warning period leading to the possible crisis, then remember that hard work is involved in excavating the hole. The assembly of the shell can be completed in a full day by two people. The time required to excavate will depend on your ability but with two fit people it should be possible to carry out all the necessary work within a week.

Ensure that the excavation is safe at all times by cutting the earth back to the natural angle of repose or by adequately strutting the sides. Never trust the sides of a trench or any excavation unless you are certain that it is safe. If in doubt then seek professional advice.

6.6 Alternative shapes and future development work

In some cases there may be a requirement for peace-time built shelters to be installed with the external ground remaining flat. For such underground buried structures the cylinder or sphere shape is best. The designer is advised to aim for a cylinder with about 1.5 metres of earth cover to achieve the best form of protection for this kind of shelter against all effects.

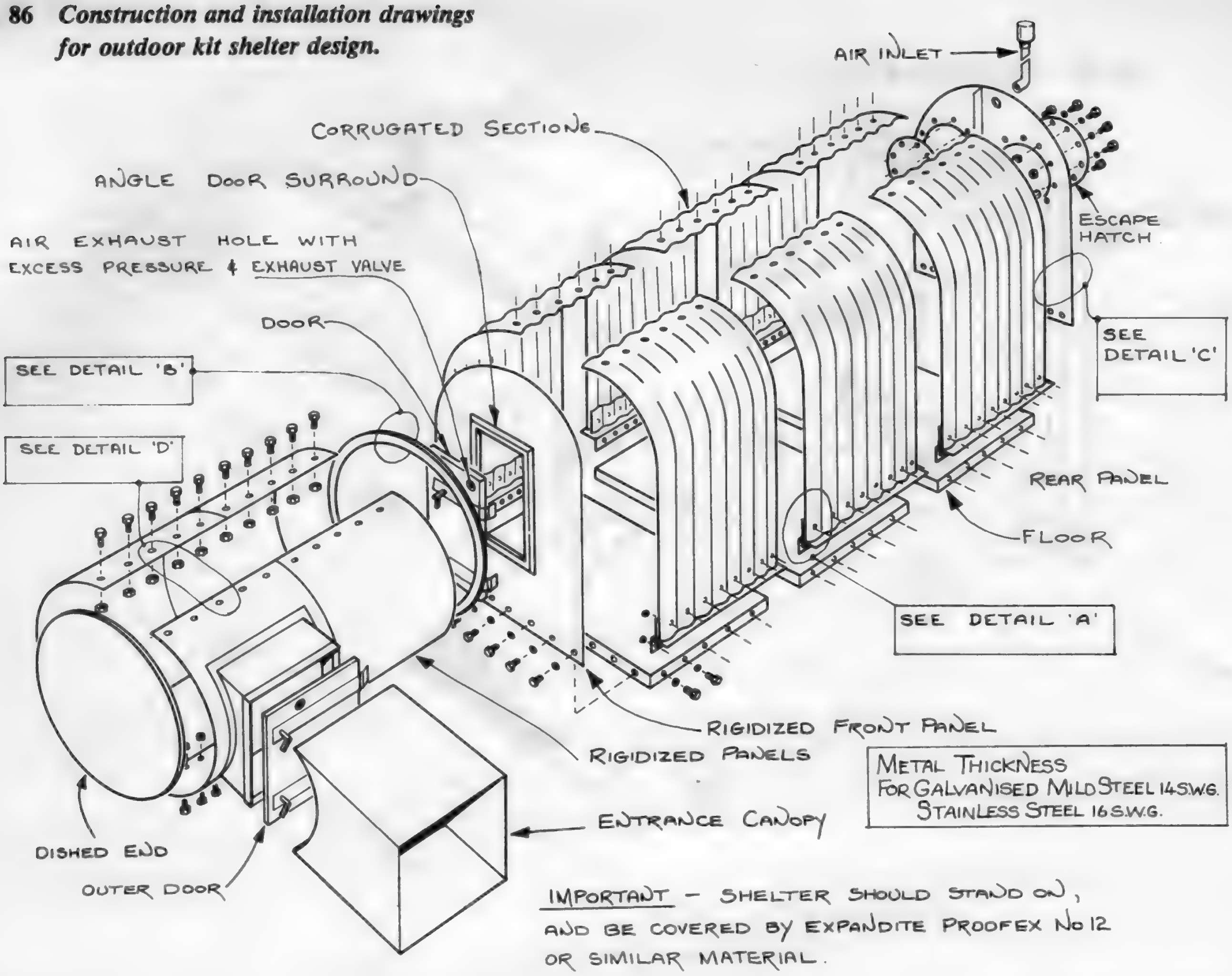
It is intended that further development work and trials be carried out on deeply buried thin walled shells and that information will be published in due course.

6.7 Occupying the shelter

1. During the initial period of occupation when the shelter is closed down and until after the blast and INR phase has passed, the following points should be observed:
   a. The shelter must be occupied and completely closed except for the air ventilation points, a substantial wall of sand bags must be placed against the outer door.
   b. Occupants must be located at low level within the shelter and there must not be anything loosely stored overhead.
   c. The sleeping level should be situated about 600 mm above the floor of the shelter. All stores and equipment should be located beneath the sleeping level.

2. When the blast and INR hazard has passed:
   a. Refer to the guidance notes for information on when and how long you may leave the shelter for short periods and for how long you need stay in the shelter.
   b. The shelter may be re-arranged for greater comfort during the fallout period by using overhead bunks or shelves and by placing the toilet facilities in the outer tunnel.
   c. A few sandbags will have to be removed when leaving the shelter but it is advisable that these be replaced when the occupants return.

Fig. 86 ***Construction and installation drawings for outdoor kit shelter design.***



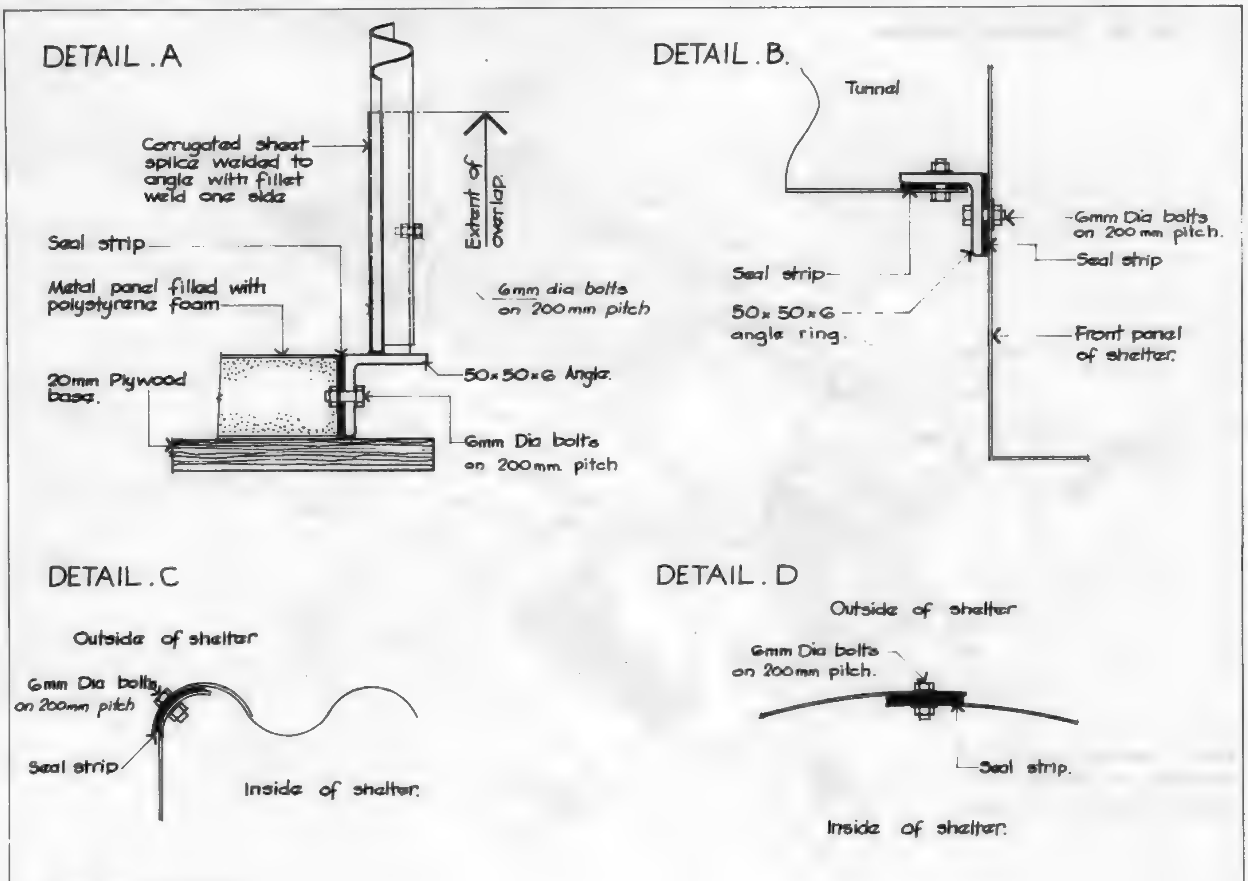


Fig. 87 ***Details***

Fig. 88 *End panels and door*

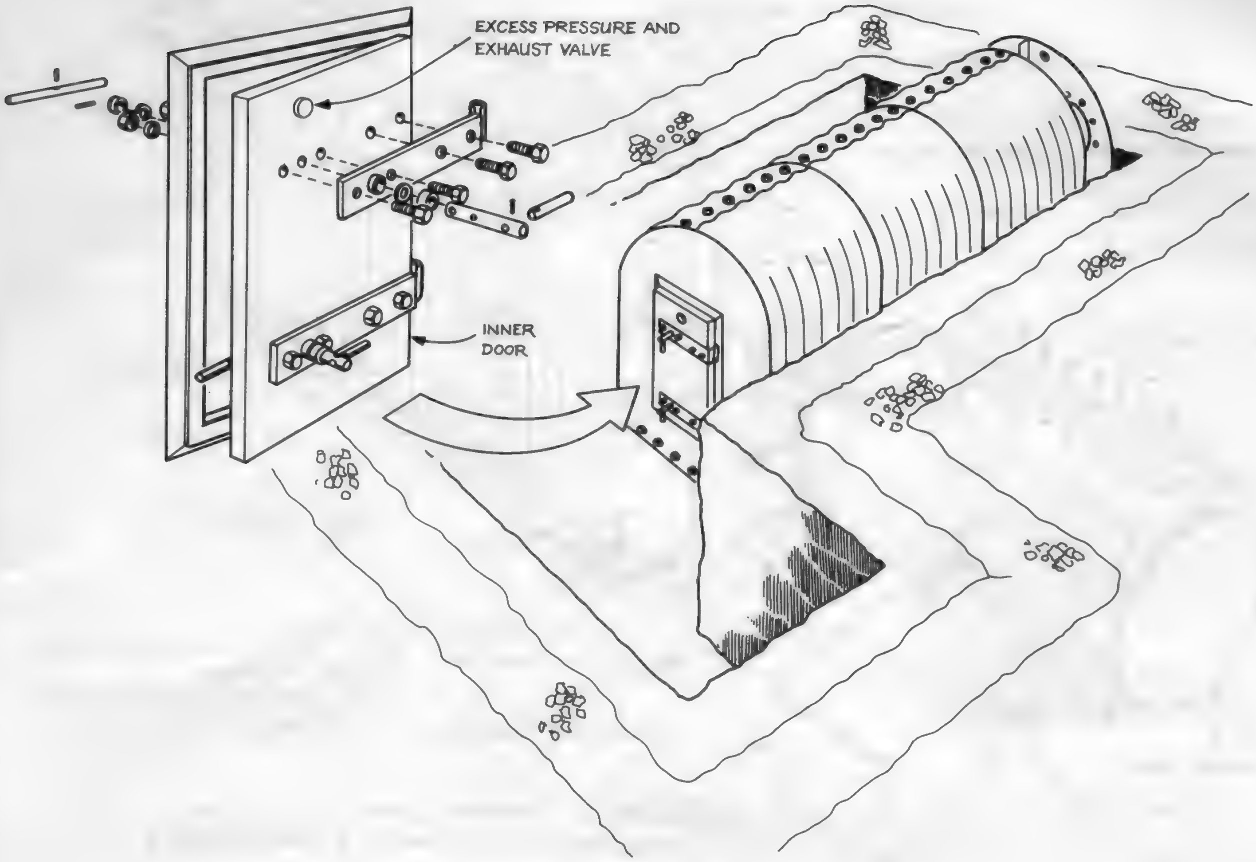


Fig. 89 *Tunnel in position*

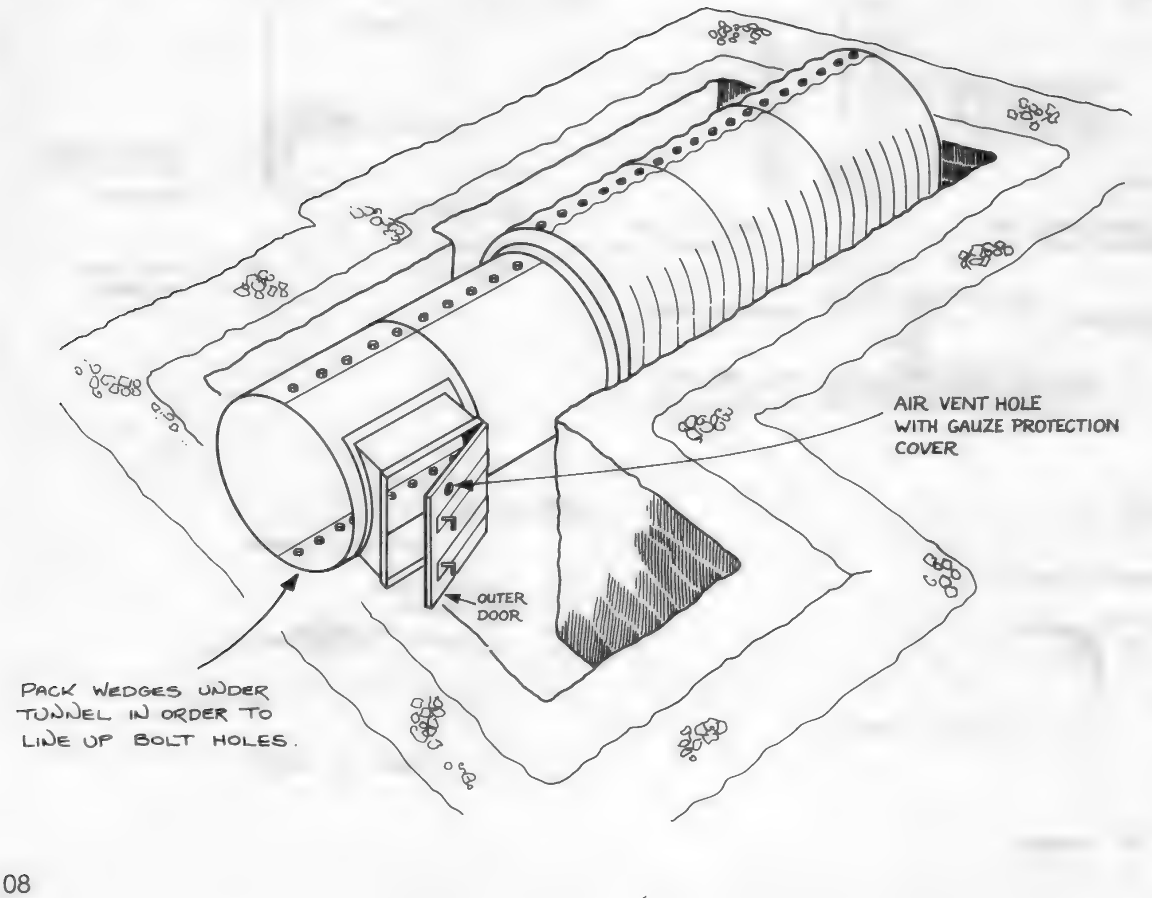


Fig. 90 *Final construction*

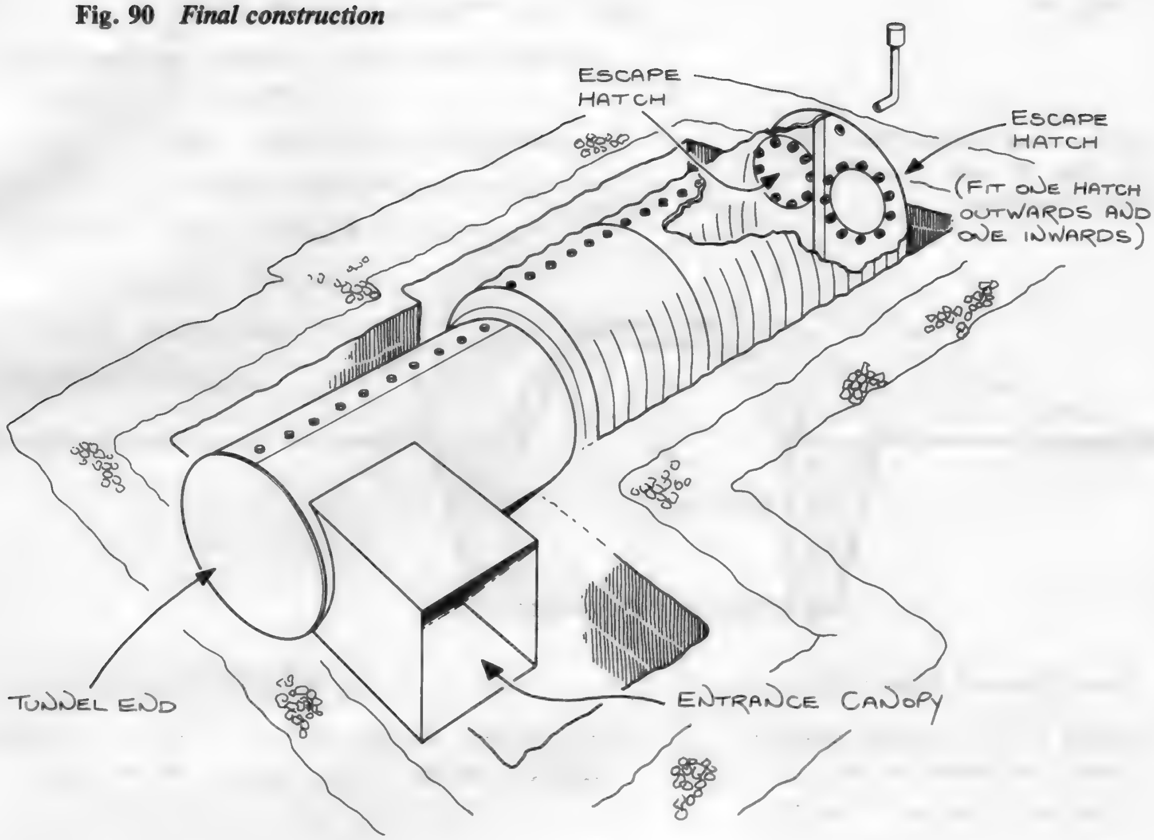


Fig. 91 *Earth cover*

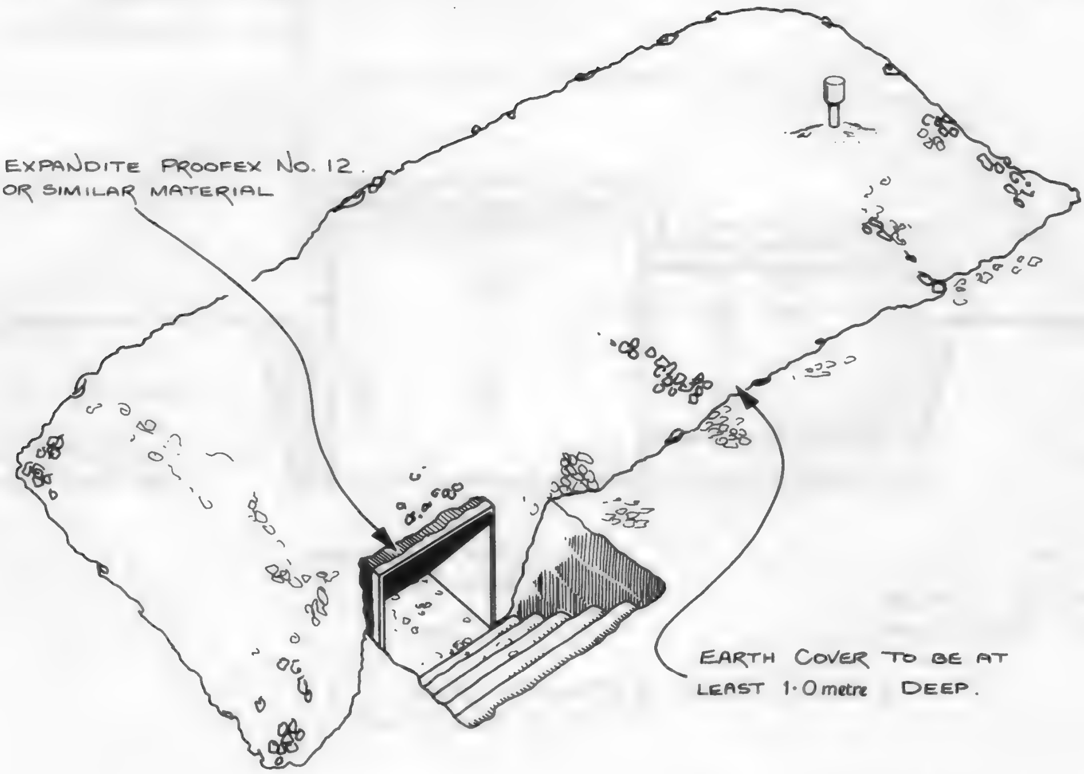
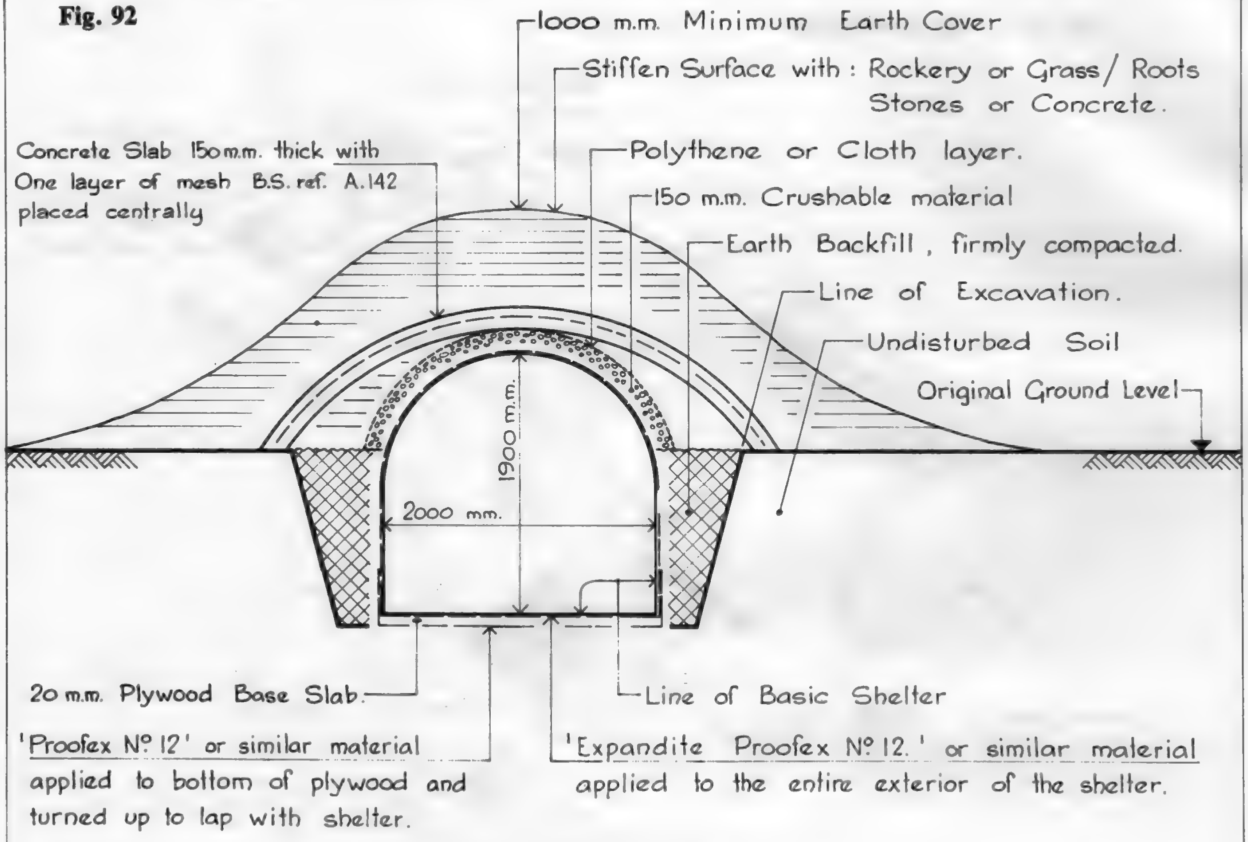
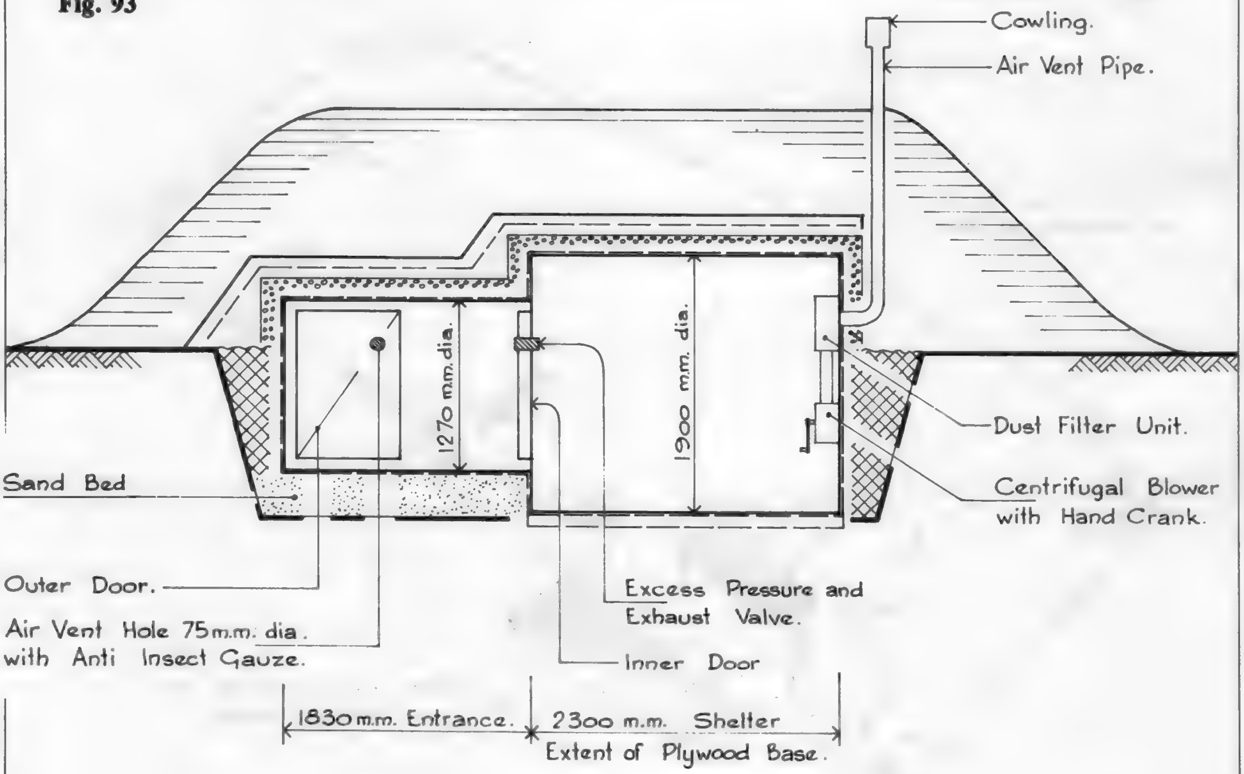


Fig. 92



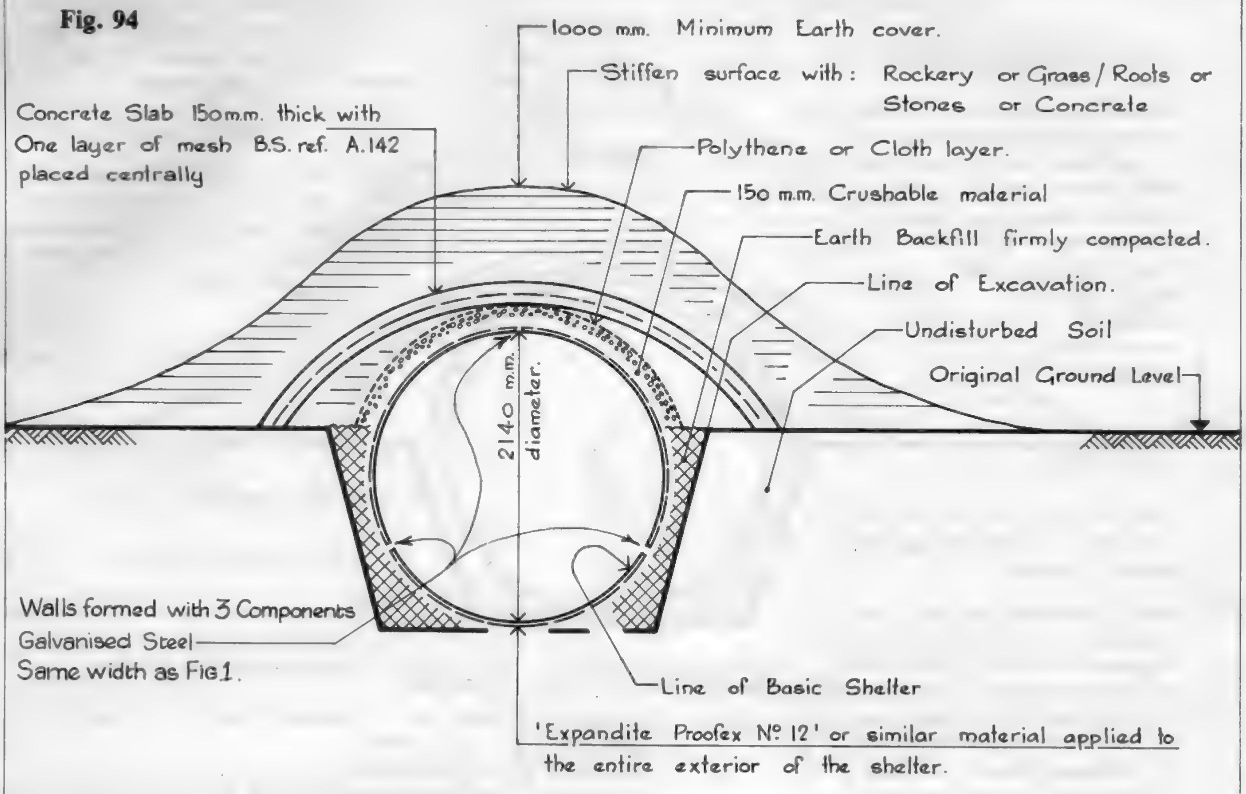
TYPICAL CROSS SECTION : (FLAT BOTTOM)

Fig. 93



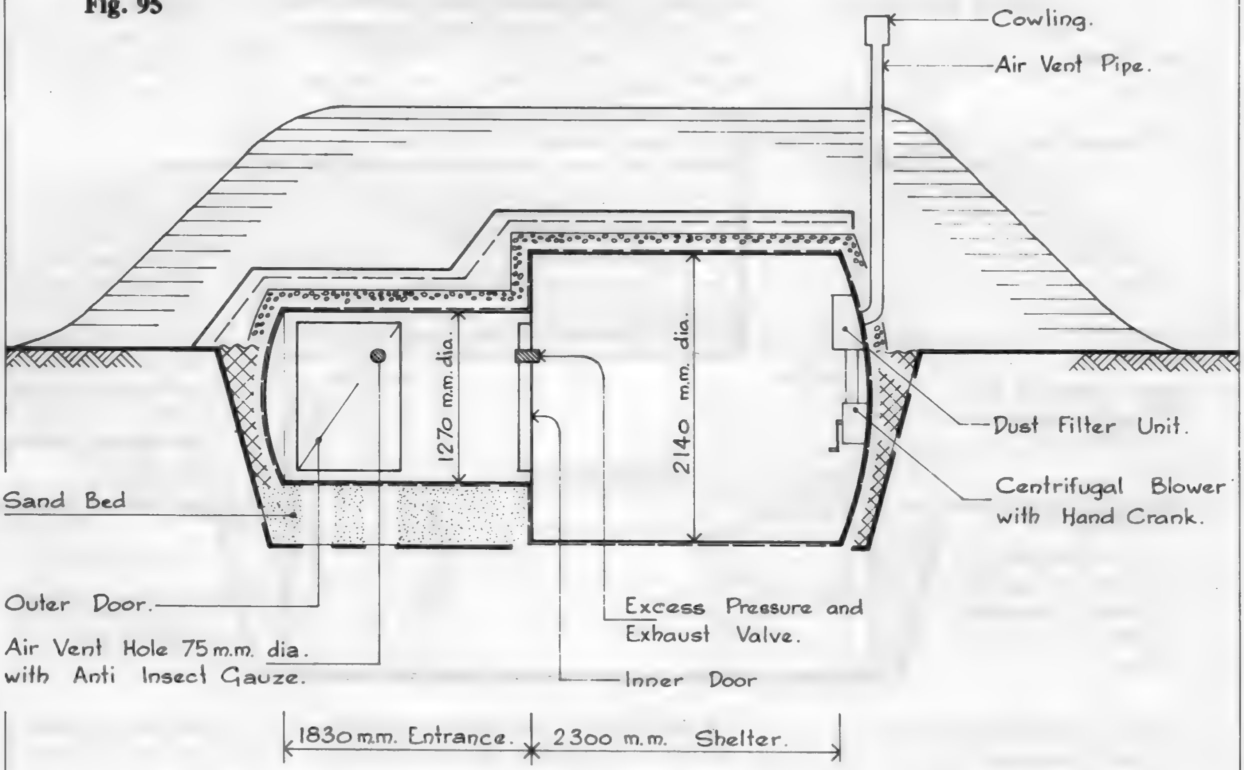
LONGITUDINAL SECTION : (FLAT BOTTOM)

Fig. 94

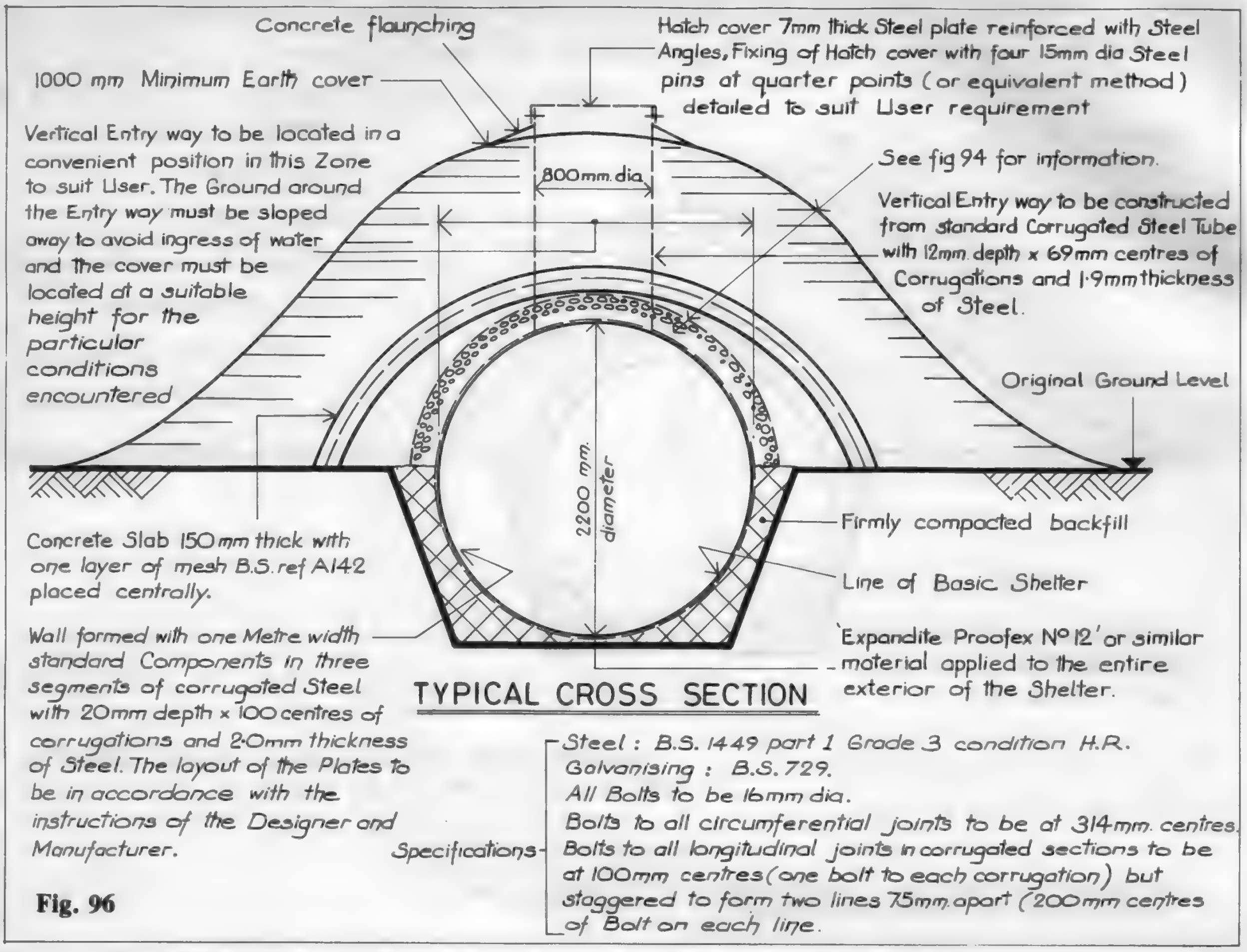


TYPICAL CROSS SECTION : (CIRCULAR)

Fig. 95

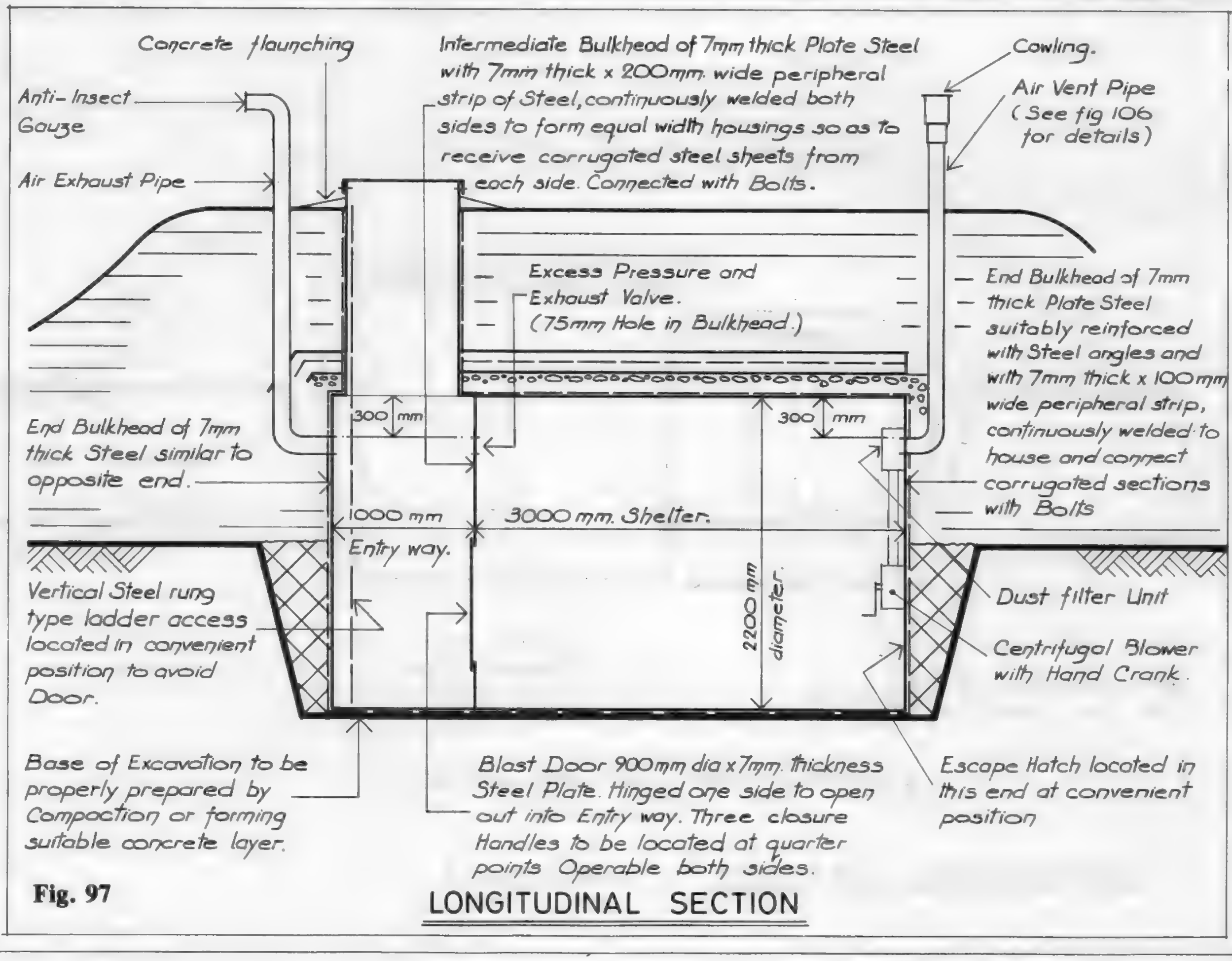


LONGITUDINAL SECTION : (CIRCULAR)



Concrete flaunching
1000 mm Minimum Earth cover
Hatch cover 7mm thick Steel plate reinforced with Steel Angles, Fixing of Hatch cover with four 15mm dia Steel pins at quarter points (or equivalent method) detailed to suit User requirement
Vertical Entry way to be located in a convenient position in this Zone to suit User. The Ground around the Entry way must be sloped away to avoid ingress of water and the cover must be located at a suitable height for the particular conditions encountered
800mm dia
See fig 94 for information.
Vertical Entry way to be constructed from standard Corrugated Steel Tube with 12mm depth x 69mm centres of Corrugations and 1·9mm thickness of Steel.
Original Ground Level
2200 mm diameter
Firmly compacted backfill
Concrete Slab 150mm thick with one layer of mesh B.S. ref A142 placed centrally.
Line of Basic Shelter
Wall formed with one Metre width standard Components in three segments of corrugated Steel with 20mm depth x 100 centres of corrugations and 2·0mm thickness of Steel. The layout of the Plates to be in accordance with the instructions of the Designer and Manufacturer.
'Expandite Proofex Nº 12' or similar material applied to the entire exterior of the Shelter.
TYPICAL CROSS SECTION
Specifications
Steel : B.S. 1449 part 1 Grade 3 condition H.R.
Galvanising : B.S. 729.
All Bolts to be 16mm dia.
Bolts to all circumferential joints to be at 314mm centres.
Bolts to all longitudinal joints in corrugated sections to be at 100mm centres (one bolt to each corrugation) but staggered to form two lines 75mm apart (200mm centres of Bolt on each line.

Fig. 96



Concrete flaunching
Intermediate Bulkhead of 7mm thick Plate Steel with 7mm thick x 200mm wide peripheral strip of Steel, continuously welded both sides to form equal width housings so as to receive corrugated steel sheets from each side. Connected with Bolts.
Cowling.
Air Vent Pipe (See fig 106 for details)
Anti-Insect Gauze
Air Exhaust Pipe
Excess Pressure and Exhaust Valve. (75mm Hole in Bulkhead.)
End Bulkhead of 7mm thick Plate Steel suitably reinforced with Steel angles and with 7mm thick x 100mm wide peripheral strip, continuously welded to house and connect corrugated sections with Bolts
300 mm
300 mm
End Bulkhead of 7mm thick Steel similar to opposite end.
1000 mm
3000 mm Shelter.
Entry way.
2200 mm diameter.
Vertical Steel rung type ladder access located in convenient position to avoid Door.
Dust filter Unit
Centrifugal Blower with Hand Crank.
Base of Excavation to be properly prepared by Compaction or forming suitable concrete layer.
Blast Door 900mm dia x 7mm thickness Steel Plate. Hinged one side to open out into Entry way. Three closure Handles to be located at quarter points Operable both sides.
Escape Hatch located in this end at convenient position
LONGITUDINAL SECTION

Fig. 97

Chapter 7
Permanent concrete shelter design

7.1 General specification

The shelter is designed for erection on private land by a building contractor to the requirements of the owner. In their own interests any persons proposing to erect such a shelter are strongly advised to seek professional advice preferably from an architect and/or a civil/structural engineer. The structure is unsuitable for erection by unskilled and unsupervised labour. Particular attention is drawn to the *Notes, Design assumptions* and *Specification of materials* which preceed the drawings. Adherence to these requirements is essential.

The shelter is designed as a protection against the radiation from fallout and it would, if properly constructed, give a protective factor of 300, i.e., the radiation received in such a shelter would be 1/300 of that which would be received if a person were in the open. Additionally it would also withstand blast pressures of up to 105 kiloPascals (15 pounds per square inch) and it would withstand many of the fire effects of nuclear and other explosions. A more deeply buried arrangement for this shelter is shown in Fig. 110 which substantially enhances the protection afforded.

It is designed to accommodate six adults, although instructions are given on the drawings for modifications, increasing the length, but not the width, by 750 mm for each two adults extra. This extension of length can be carried out up to a total of 2.25 metres extra to provide a total accommodation for 12 persons. The degree of protection stems from the density of the materials used; the reinforcement of the roof, floor and walls; and the amount of earth surrounding the whole structure.

7.2 Ventilation

The design incorporates two air shafts – intake and exhaust, The ventilation pipe is vulnerable and should be protected against damage and missile debris. The exhaust shaft contains a non-return valve. These air shafts must not be obstructed by any furniture or fittings. A hand-operated blower should be fitted as shown in the drawings. The amount of fresh air required to ventilate the shelter satisfactorily is about 1 cubic metre per minute (35 cubic feet per minute). If a pump delivering 4 cubic metres per minute (140 cubic feet per minute) is installed this needs to be operated for about 15 minutes every hour, for the standard six-person shelter increasing this time to 30 minutes *pro rata* for the extended versions. During the periods in which the hand pump is not being operated the cap should be removed from the alternative air channel to allow for any natural ventilation promoted by surface winds.

No filtration (other than the coarse mesh indicated on the drawing) is necessary for the air intake. The nature of fallout particles is such that they will not be drawn into the air intake even when the pump is in operation. Similarly no blast valves are necessary if the details of the air intake and exhaust are adhered to.

7.3 Equipment, furniture and fittings

All other equipment, toilet facilities, water containers, food containers, cupboards, cooking facilities, beds, etc. may, at the discretion of the owner, be incorporated after erection or may be transferred and adapted, perhaps from other household uses during a crisis. If mains electricity and piped water are incorporated it would be unwise to assume that supplies would be available immediately after attack and suitable contingency arrangements should be made.

7.4 Excavation, backfill, and earth cover

The excavation should have side slopes gradual enough to prevent caving, or appropriate shoring should be provided. Materials used for backfill should have debris, roots and large stones removed before placement. The ground under the floor slab should be level to provide uniform bearing conditions for the structure. The area immediately around the shelter should be sloped away at a minimum gradient of 1:100 to provide good drainage.

Reinforced concrete, and waterproofing

The reinforced concrete and waterproofing work should conform with all the relevant Building Regulations and British Standard Codes of Practice prescribing the quality of materials and standards of workmanship.

NOTES.

1. Exterior walls, roof slab and floor slab shall be waterproofed with an approved membrane fixed to the external surfaces. (Bituthene with welded seams or similar).

2. The reinforced concrete construction together with the waterproof membrane should provide a watertight structure in the vast majority of cases.

3. For cases where leakages occur a sump is provided at the lowest level to enable water to collect. In such cases electrically powered automatic pumps should be installed together with a stand-by hand operated pump.

4. There are a number of commercially produced metal roof trap doors that will adequately serve as a shelter hatch. However as long as the door is weatherproof and durable, a job made galvanised sheet metal covered wood hatch is suitable

DESIGN ASSUMPTIONS.

1. The minimum safe bearing pressure of the soil at floor level should be 30 KN per m^2 (0·26 tons per ft^2). In circumstances where weaker soils exist it may be necessary to extend the floor slab beyond the perimeter walls. In such cases advice should be sought from the Local Authority or from a professionally qualified engineer.

2. Sulphate resisting cement should be used for all concrete construction in circumstances where soils contain sulphates to a dangerous degree.

3. The structure has been designed to be stable against flotation for all levels of ground water.

SPECIFICATION OF MATERIALS.

1. All reinforcement to be mild steel to B.S. 4449.

2. All concrete to have a strength of 30 N per mm^2 at 28 days and to be vibrated to produce a dense watertight concrete.

3. All exposed steelwork to be galvanised or similarly protected.

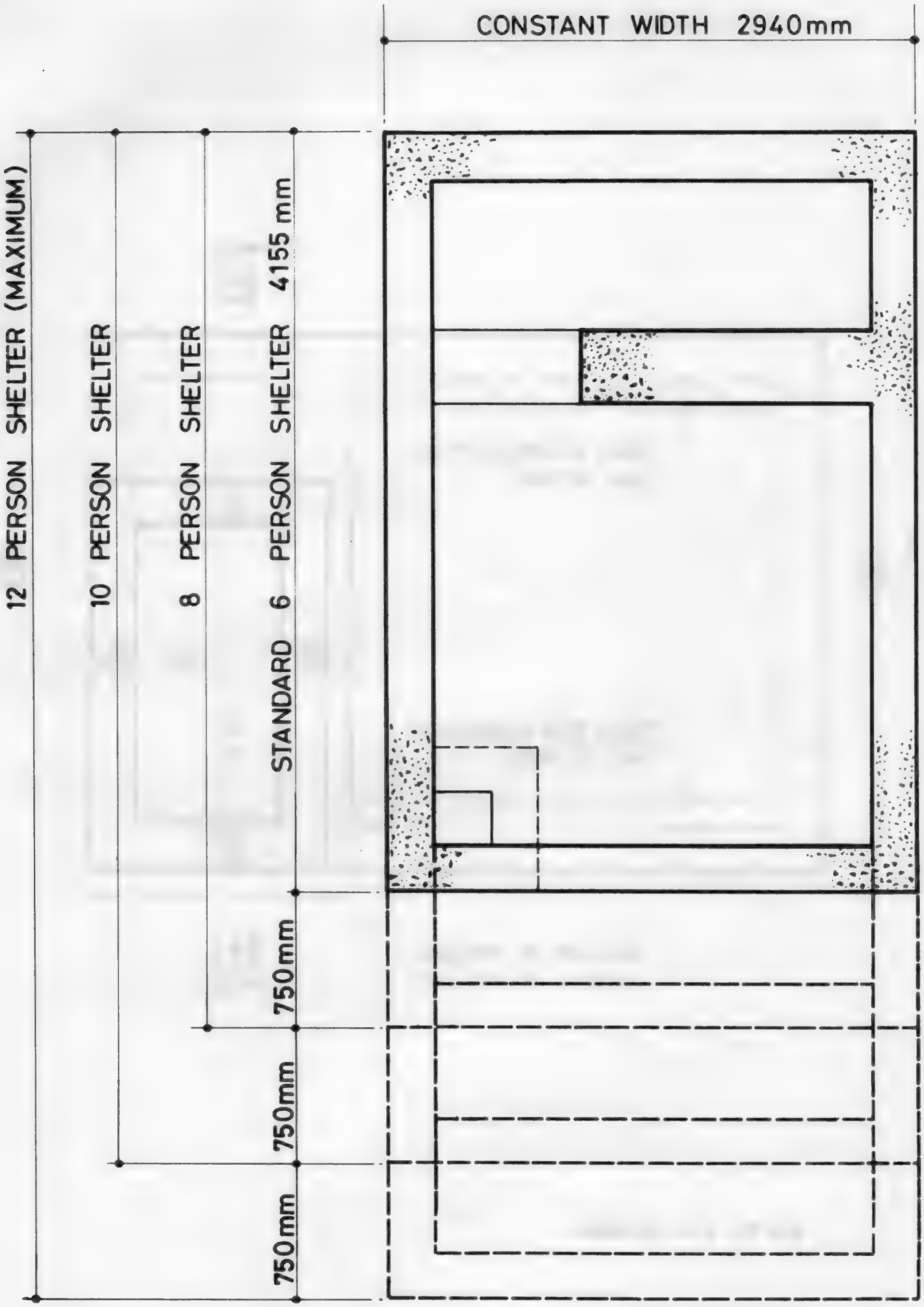


Fig. 98 *Various plan sizes*

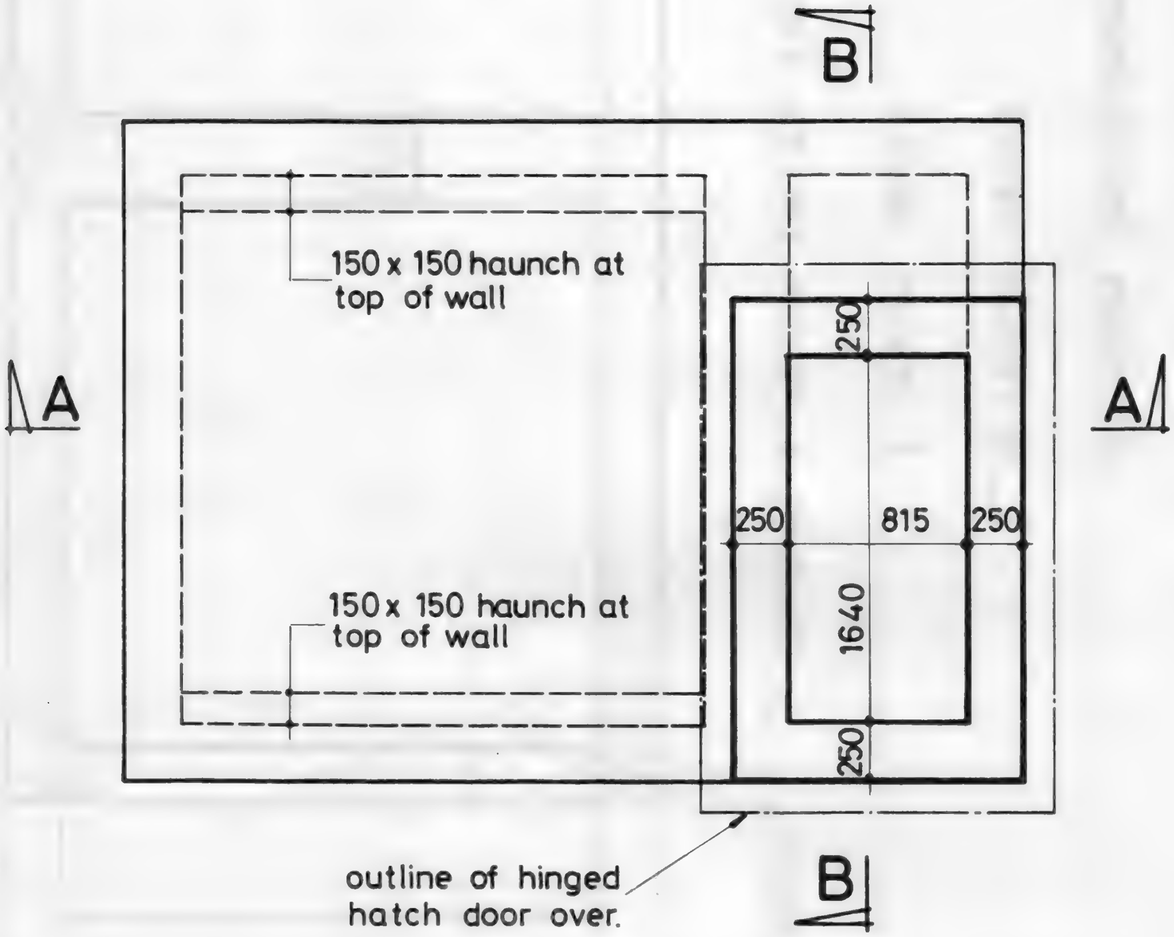


Fig. 99 *Plan of shelter*

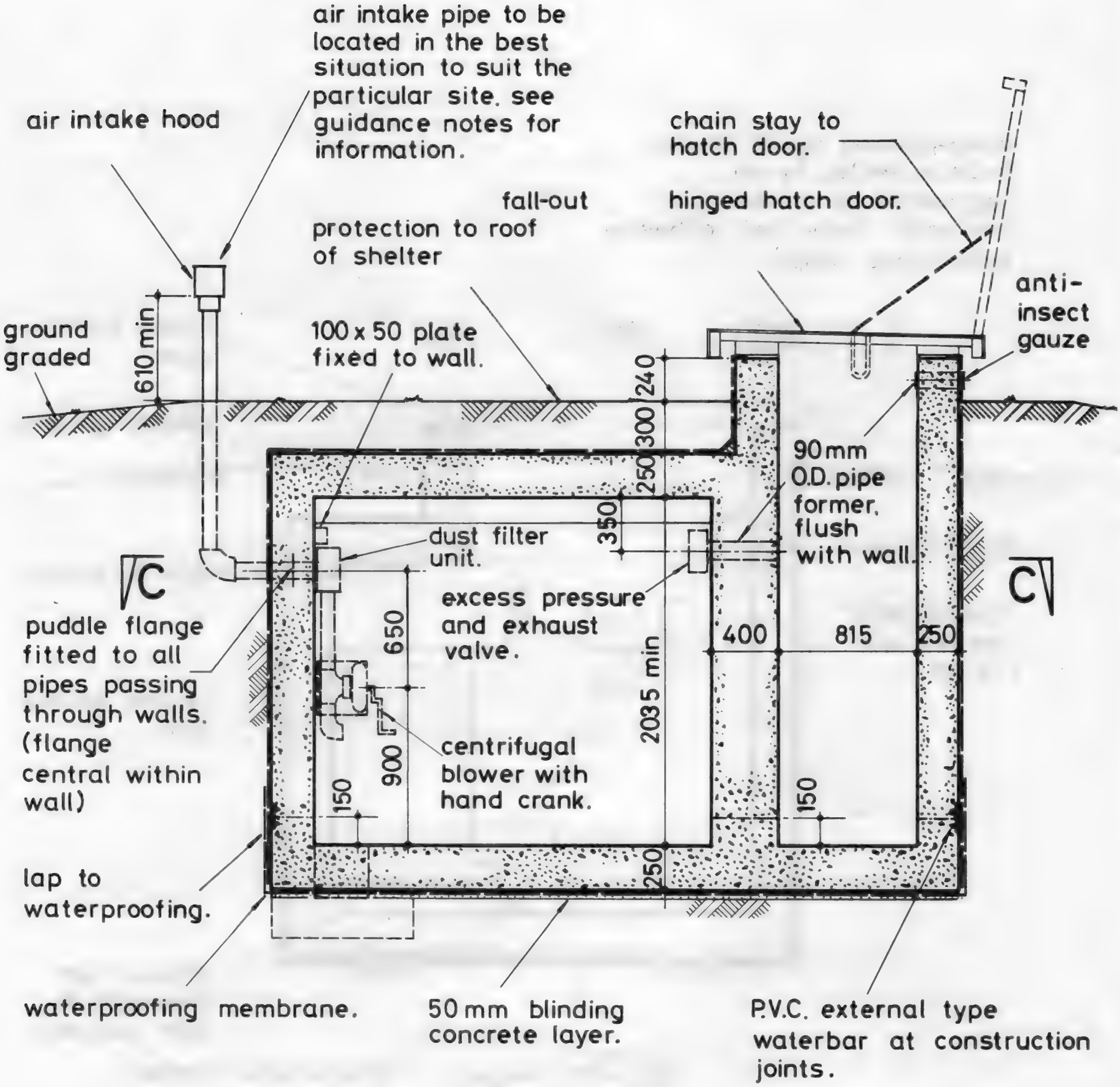


Fig. 100 *Section A–A*

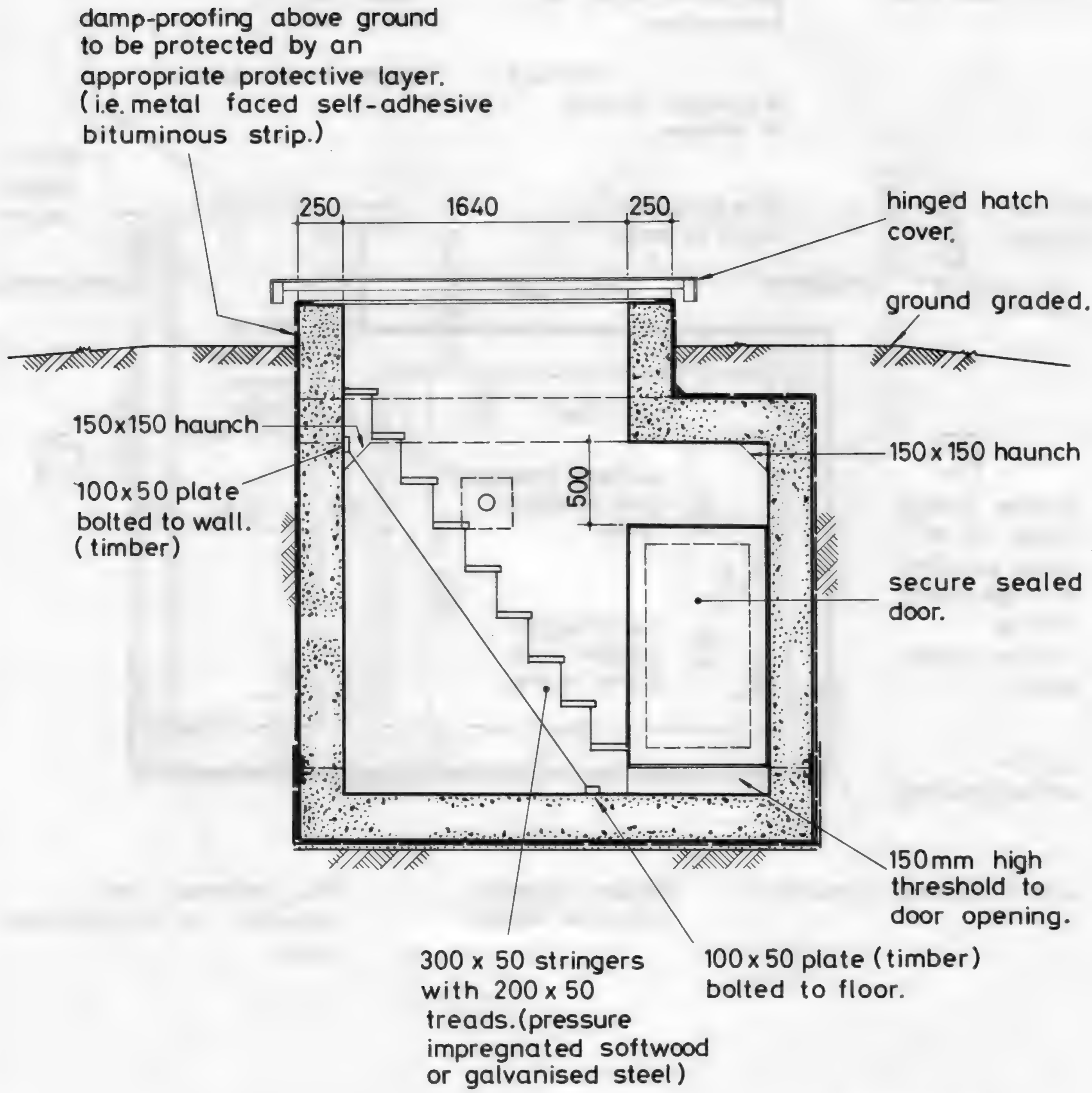


Fig. 101 *Section B–B*

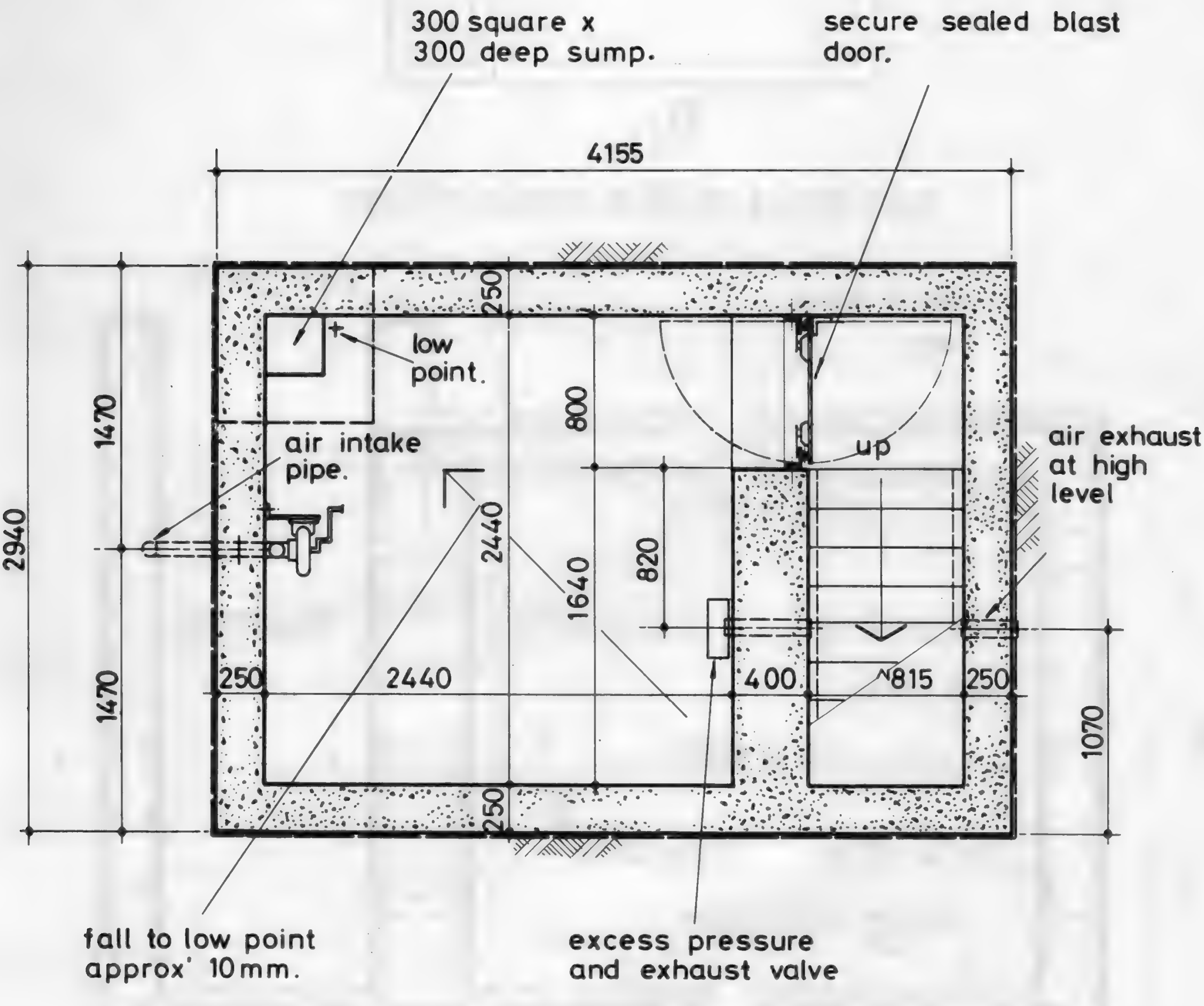
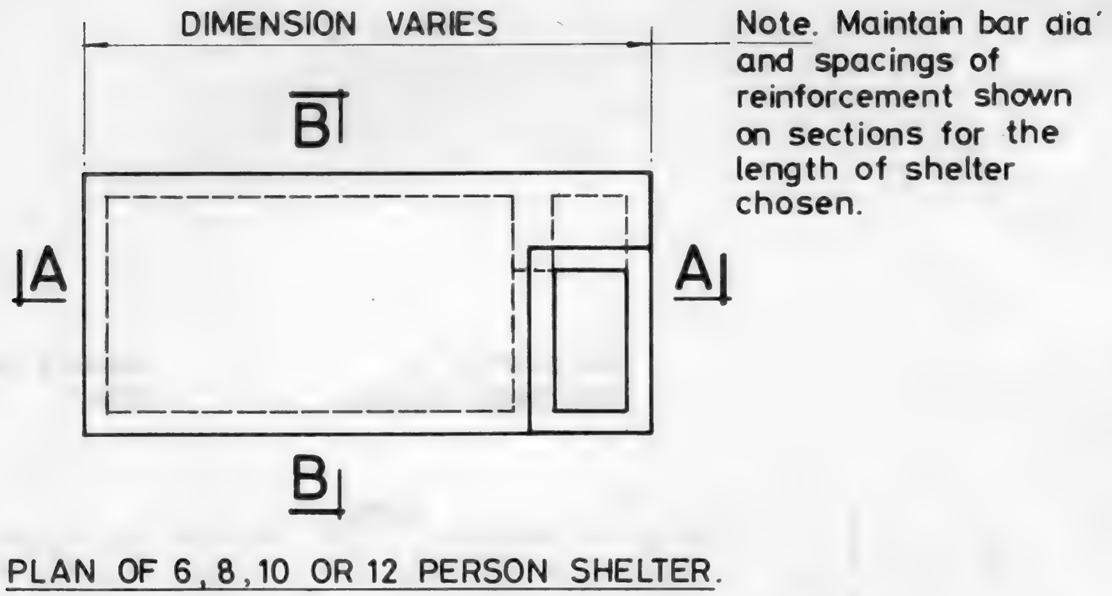


Fig. 102 *Plan C–C*



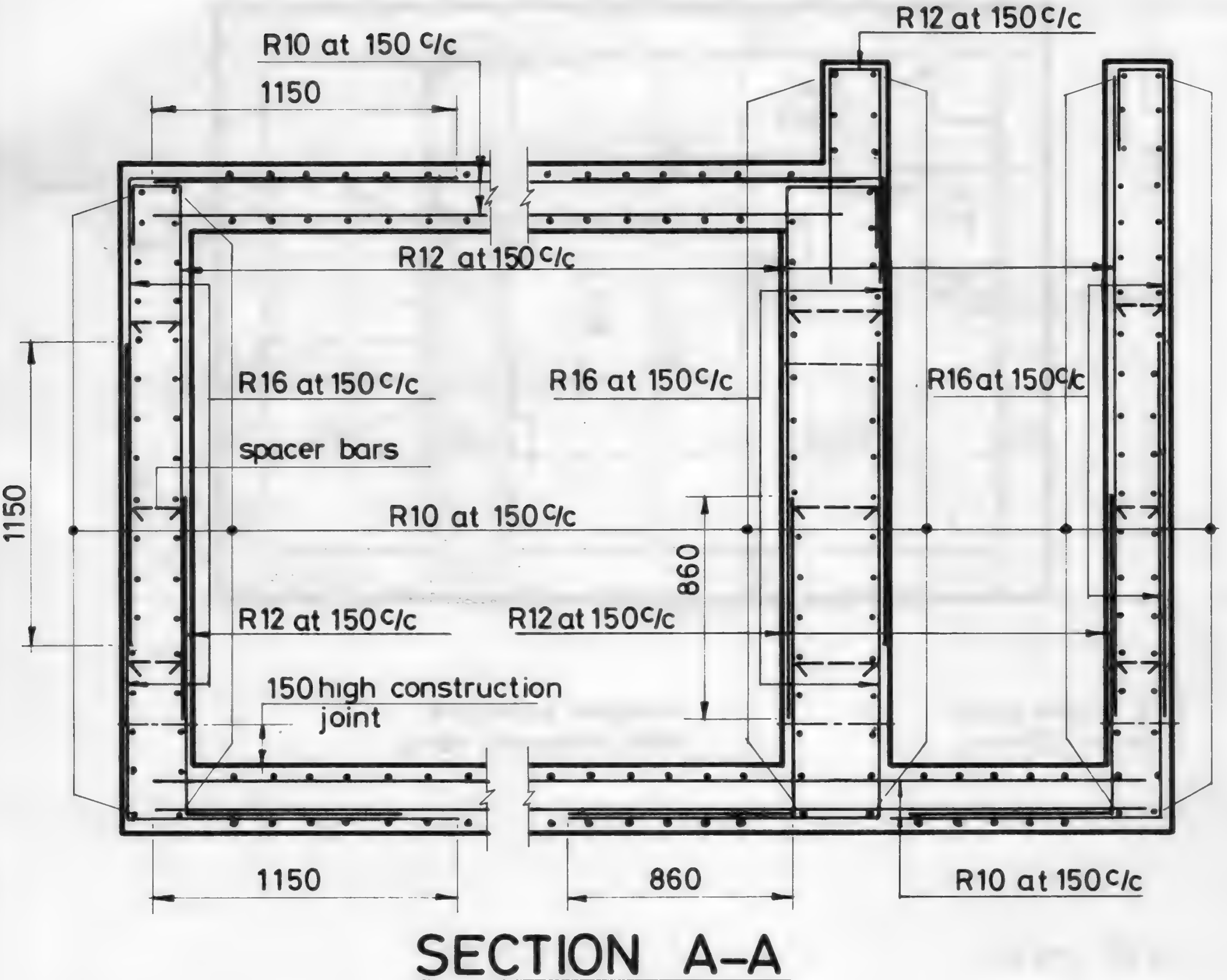
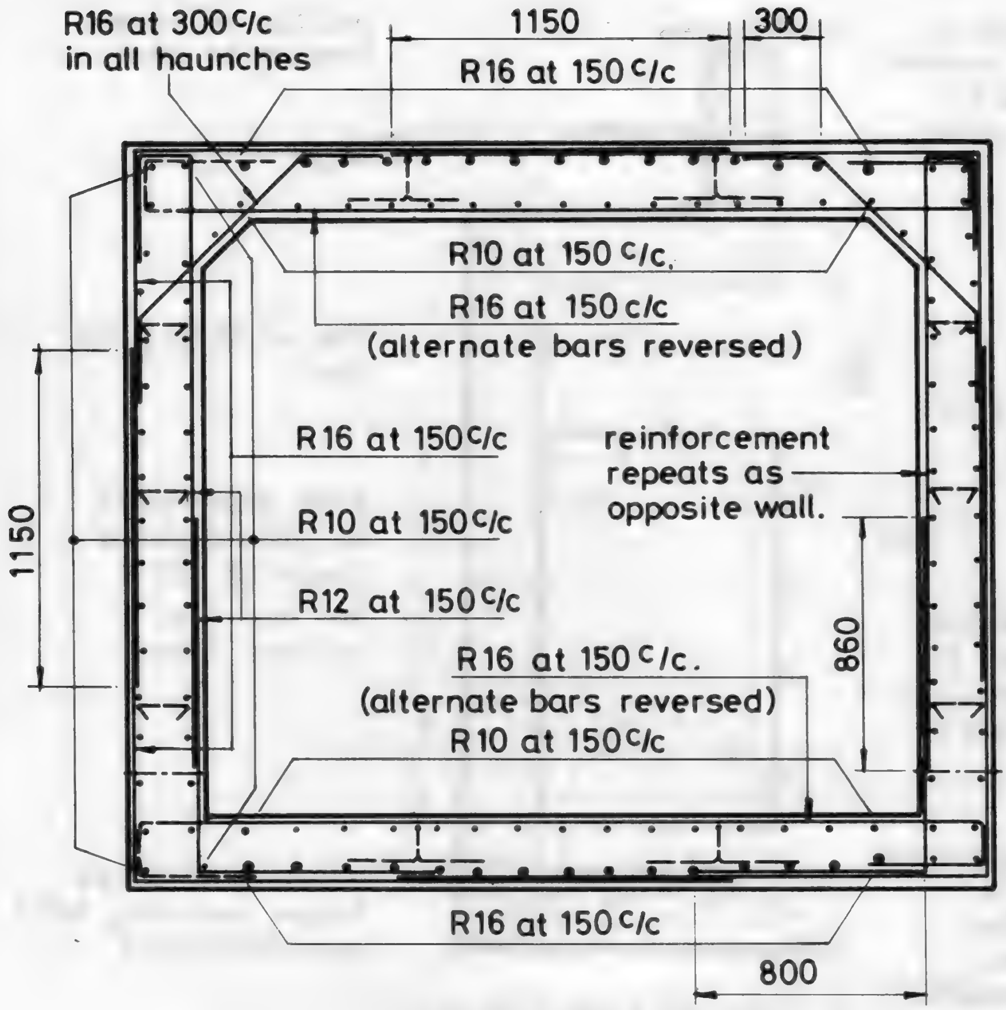
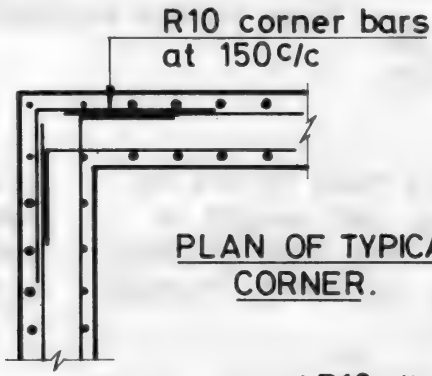


Fig. 103 *Reinforced concrete details. Shelter design for blast effects of 15 psi peak overpressure*

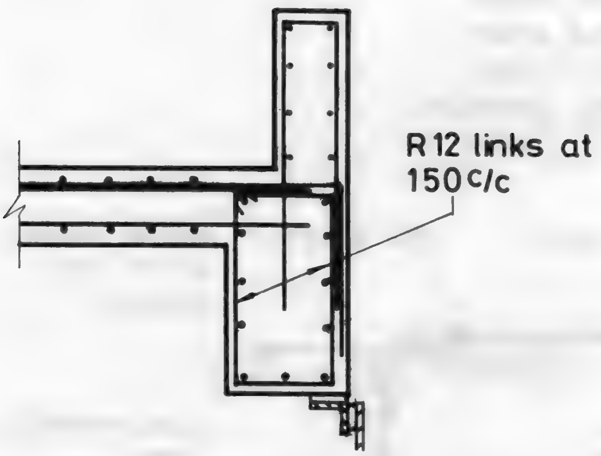


NOTES.
R16 = 16mm dia mild steel reinforcing rods.
Minimum cover to any reinforcement is to be 50mm.
An adequate number of spacer bars is to be provided between layers of reinforcement to maintain the required cover.

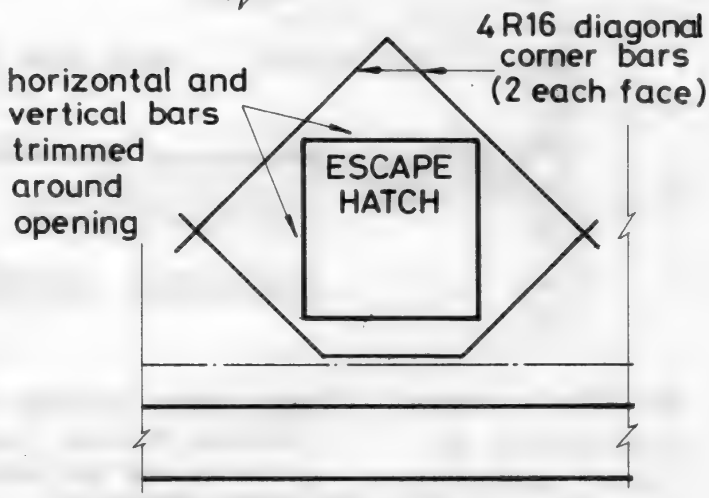
SECTION B-B



PLAN OF TYPICAL CORNER.



VERTICAL SECTION THROUGH DOWNSTAND BEAM OVER DOOR.



ELEVATION OF ESCAPE HATCH IN WALL.

Fig. 104 *Reinforced concrete details. Shelter design for blast effects of 15 psi peak overpressure*

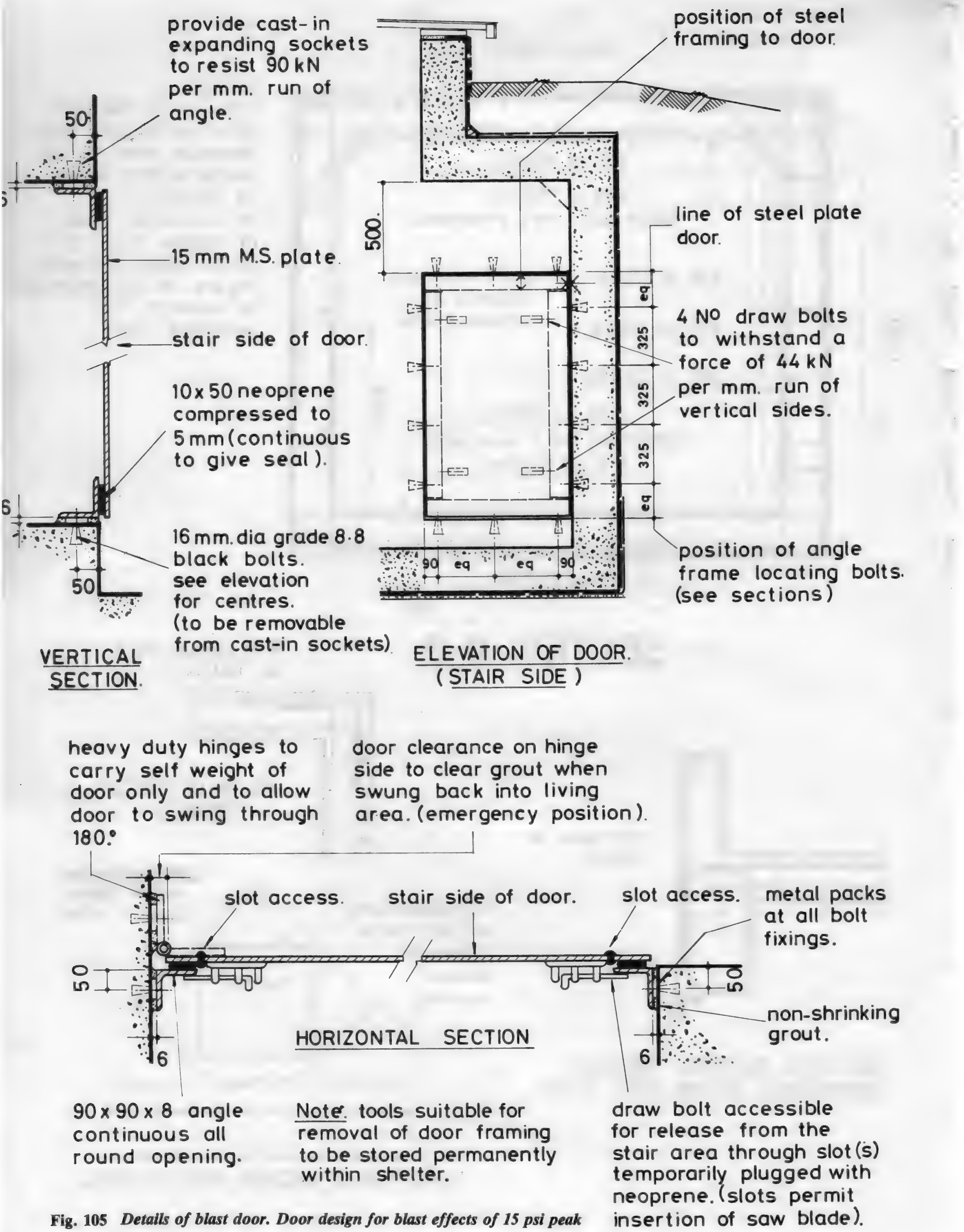


Fig. 105 *Details of blast door. Door design for blast effects of 15 psi peak overpressure*

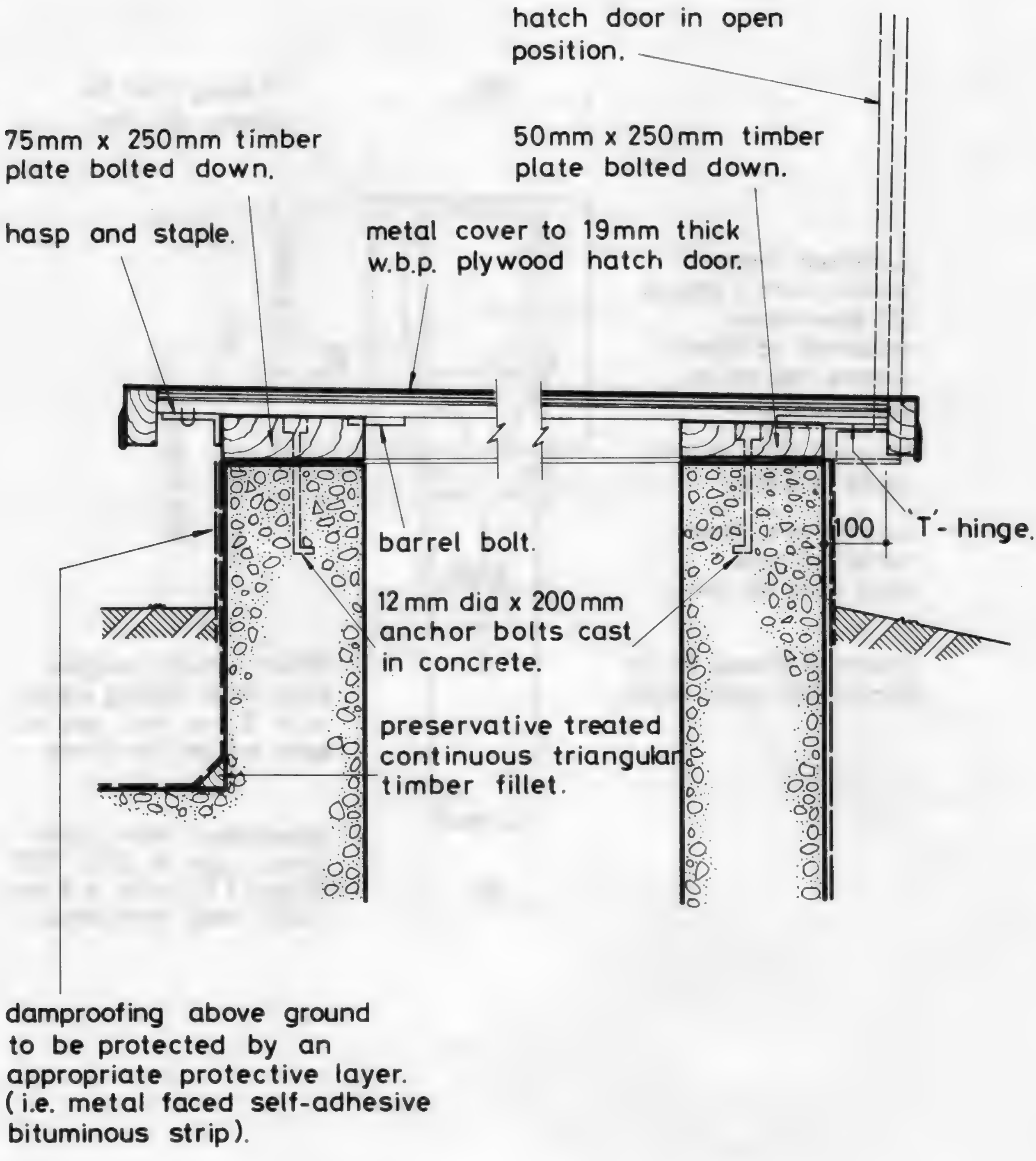


Fig. 106 *Detail of hatch opening*

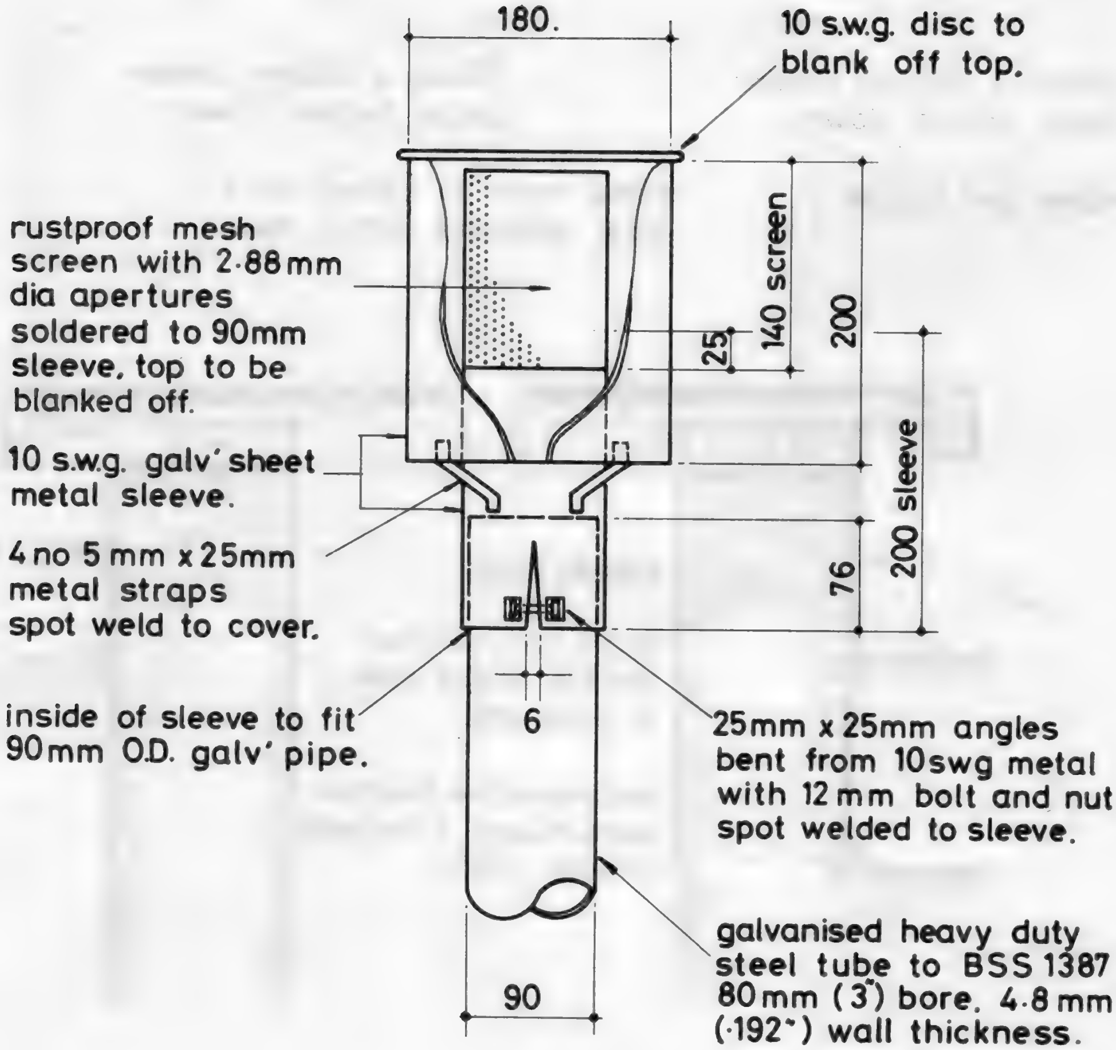


Fig. 107 *Air intake hood detail*

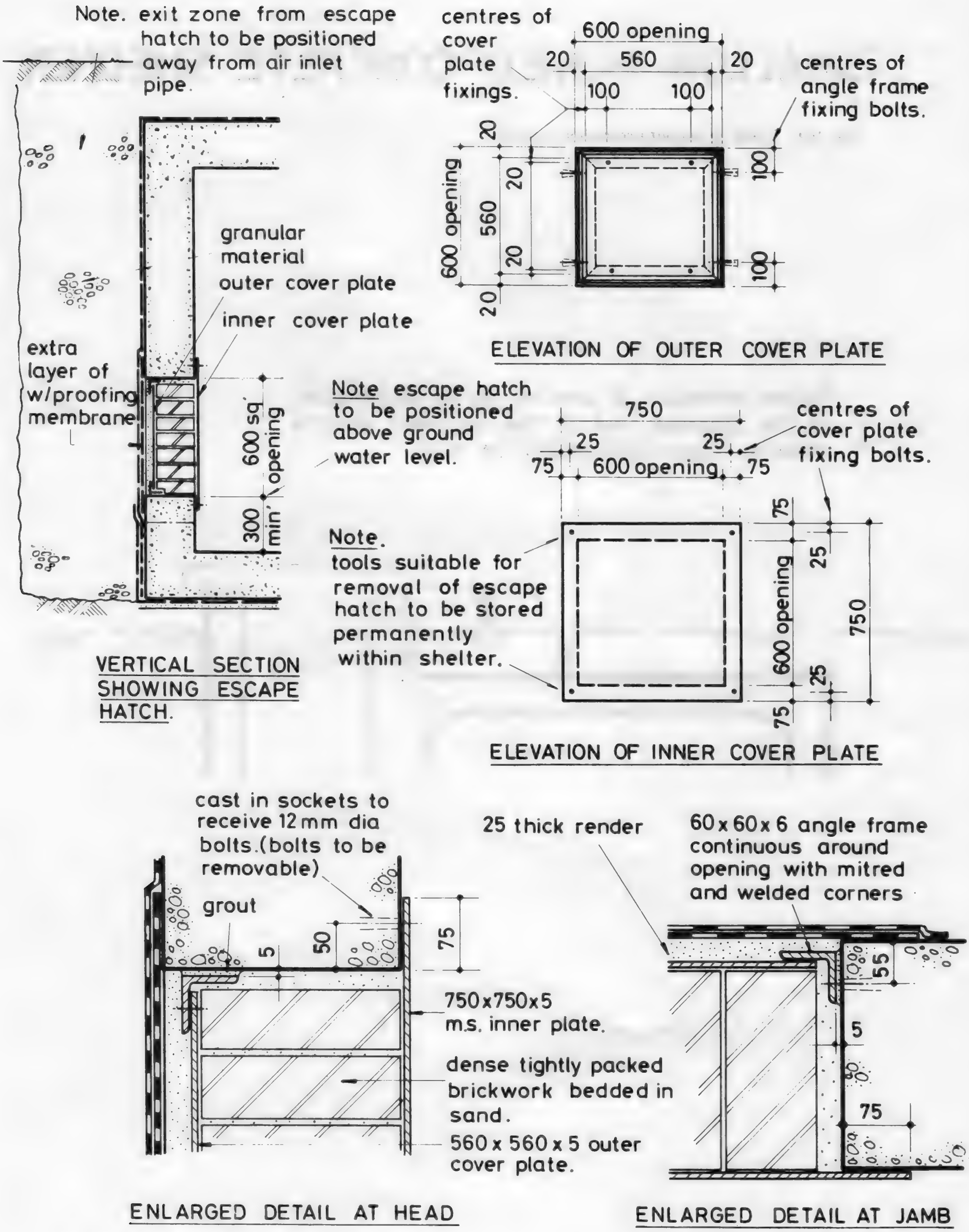


Fig. 108 *Details of escape hatch*

"SHALLOW BURIED" CONCRETE SHELTER.

Fig. 109 ***Detail of fallout protection to roof***

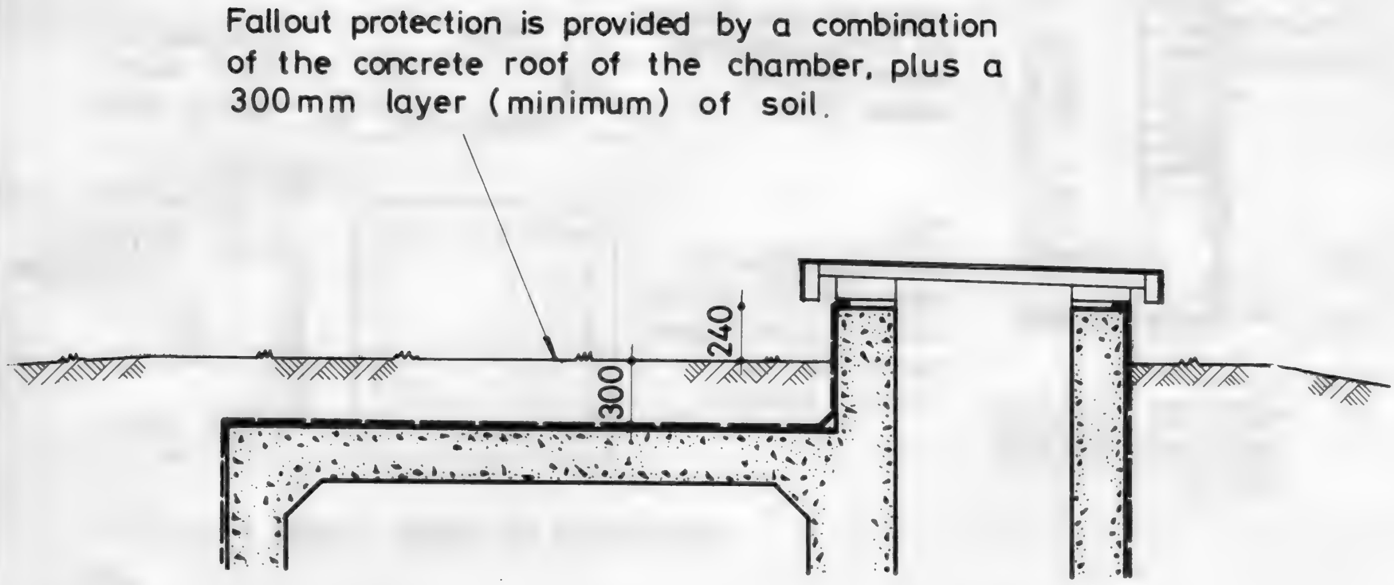
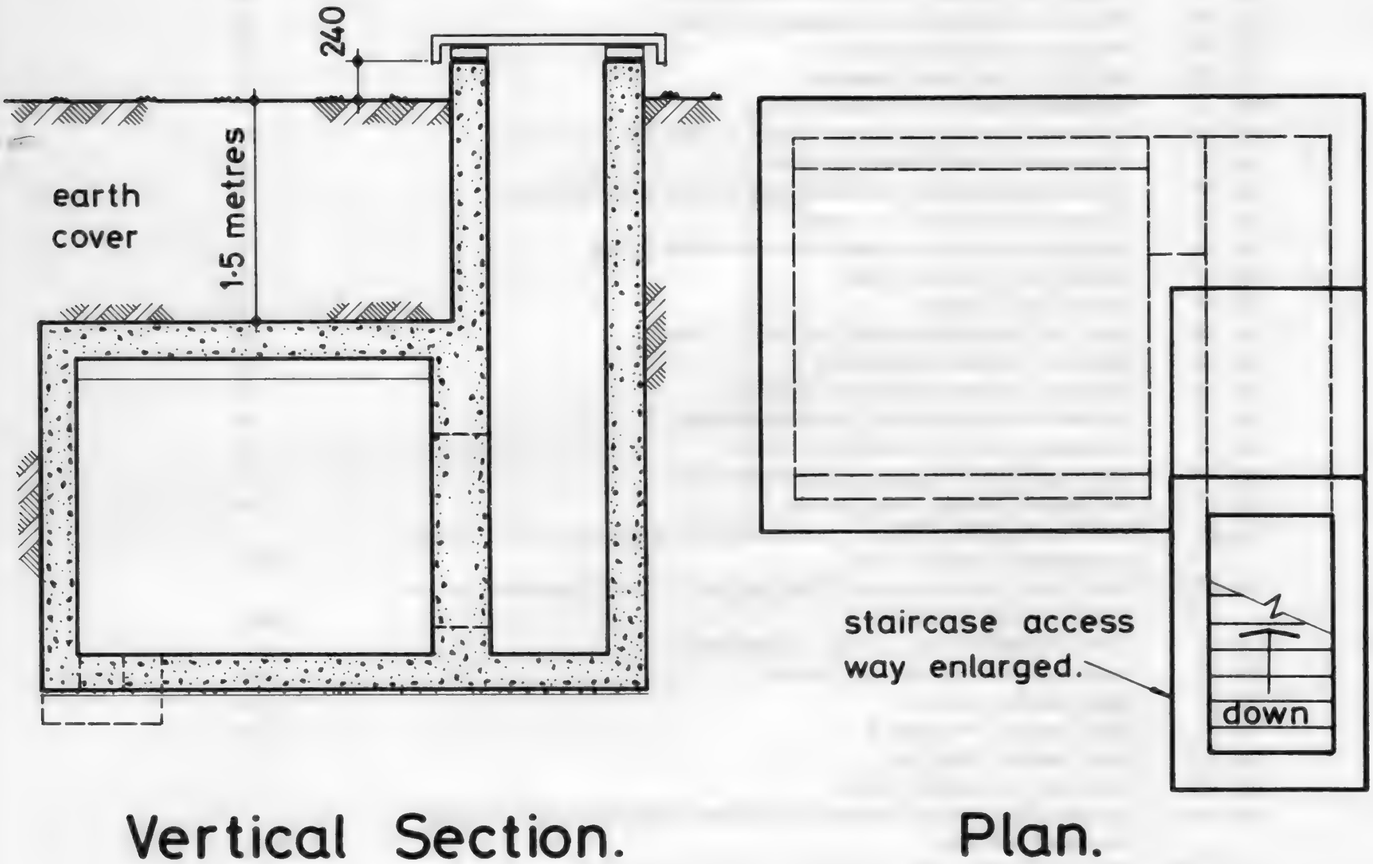


Fig. 110 *Alternative fallout protection to roof*

Option for improved resistance to the effects of fallout, initial nuclear radiation and blast.
By using the reinforced concrete shelter detailed in this pamphlet, but positioning it below ground with 1·5 metres of earth cover, the protection afforded is substantially enhanced against fallout, initial nuclear radiation and blast from the "Airslap Blast Effect", than can be achieved by "shallow burial."

In this case the staircase access way will need to be enlarged to accommodate a staircase with an acceptable slope to suit customer requirements.



GENERAL ARRANGEMENT OF THE SHELTER WITH 1·5 METRES OF EARTH COVER.

List of figures

UK NATIONAL ARCHIVES: ES 5/2
ANDERSON SHELTER TESTS AGAINST 25 KT NUCLEAR NEAR SURFACE BURST (2.7 METRES DEPTH IN SHIP)
AWRE-T1/54, 27 Aug. 1954

SECRET—GUARD

ATOMIC WEAPONS RESEARCH ESTABLISHMENT
(formerly of Ministry of Supply)

SCIENTIFIC DATA OBTAINED AT OPERATION HURRICANE
(Monte Bello Islands, Australia—October, 1952)

$$p = \frac{130 \times 10^9}{R^3} + \frac{7 \cdot 7 \times 10^6}{R^2} + \frac{13 \cdot 5 \times 10^3}{R} \text{ p.s.i.}$$

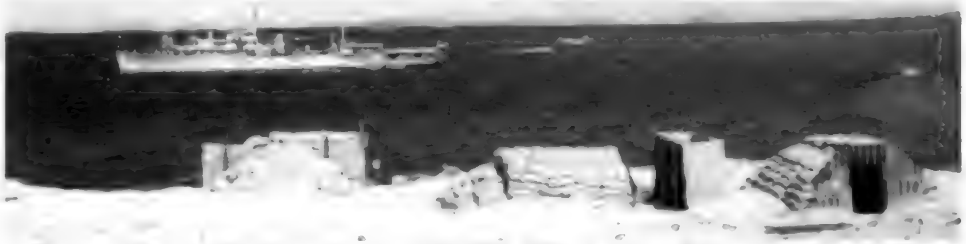


Fig. 12.1, Andersons at 1380 ft range from bomb ship shown in the photo, moored 400 yards off shore.

Left: Fig. 12.3, Andersons at 1800 ft after burst. Right: Fig. 12.4, Andersons protected by blast walls at 2760 ft.

12.1. *Blast Damage to Anderson Shelters*

At 1,380 feet, Fig. 12.1, parts of the main structure of the shelters facing towards and sideways to the explosion were blown in but the main structure of the one facing away from the explosion was intact, and would have given full protection. At 1,530 feet, Fig. 12.2, the front sheets of the shelter facing the explosion were blown into the shelter but otherwise the main structures were more or less undamaged, as were those at 1,800 feet, Fig. 12.3.

At 2,760 feet, Fig. 12.4, some of the sandbags covering the shelters were displaced and the blast walls were distorted whilst at 3,390 feet, Fig. 12.5, the effect was quite small. At these distances, the shelters were not in direct view of the explosion owing to intervening sandhills.

13. The Penetration of the Gamma Flash

13.1. *Experiments on the Protection from the Gamma Flash afforded by Slit Trenches*

13.1.1. The experiments described in this section show that slit trenches provide a considerable measure of protection from the gamma flash. From the point of view of Service and Civil Defence authorities this is one of the most important results of the trial.

13.1.2. Rectangular slit trenches 6 ft. by 2 ft. in plan and 6 ft. deep were placed at 733, 943 and 1,300 yards from the bomb and circular fox holes 2 ft. in radius and 6 ft. deep were placed at 943 and 1,300 yards.

The doses received from the flash were measured with film badges and quartz-fibre dosimeters in order to determine the variation of protection with distance, with depth and with orientation of the trench and the relative protection afforded by open and covered trenches.

In general, the slit trenches were placed broadside-on to the target vessel but at 1,300 yards one trench was placed end-on. Two trenches, one at 733 and one at 943 yards were covered with the equivalent of 11 inches of sand.

TABLE 13.1

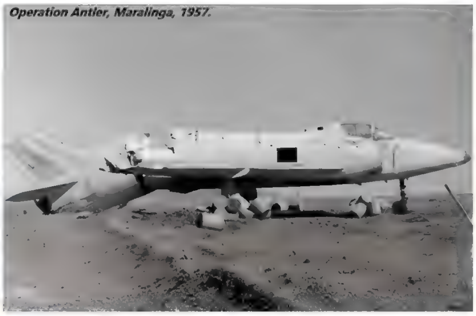
Variation of Gamma Flash Dose on Vertical Axis of Trench

Type of trench	Rectangular broadside-on open			Rectangular end-on open	Circular open		Rectangular broadside-on covered	
Distance (yards) ...	1,300	943	733	1,300	1,300	943	943	733
Surface dose (Roentgens)	300	3,000	14,000	300	300	3,000	3,000	14,000
Depth below ground level (inches)								
6 ...	150	1,000	—	230	214	1,200	(75)	—
12 ...	75	430	—	150	120	545	47·6	—
24 ...	33·3	150	584	60	54·5	188	25	(140)
36 ...	23	70	216	31·6	30	86	13	(56)
48 ...	(20)	43	100	20	17·7	48·5	7·7	(31)
60 ...	—	(37·5)	61	13·6	10·7	(33·3)	5	(23)
72 ...	—	—	(46·7)	(8·6)	7	—	(3·5)	—

Entries in brackets are extrapolations or estimates.

BUFFALO-1: Severe damage to Supermarine Swift

Operation Antler, Maralinga, 1957.



25 kt composite core (Pu239 within U235) tactical air burst on 9 October 1957, held by balloon at 300m

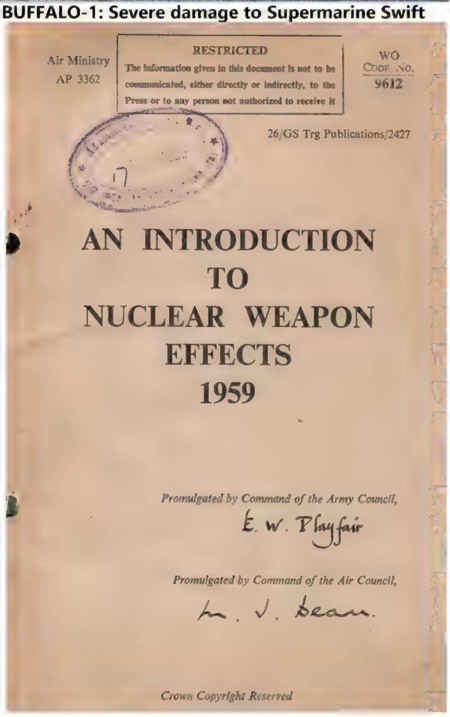


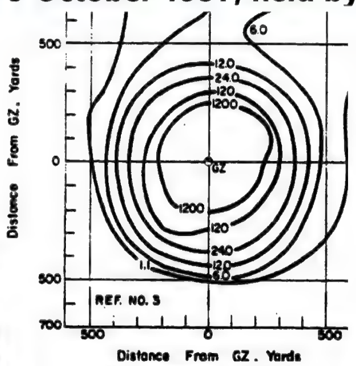
TABLE II.—Target response table for military equipment and personnel (for 20 KT and 1 KT weapon)

Equipment	Approximate peak Overpressure (psi)[1] (Taken from 20KT near surface burst results)[2]	Equivalent scaled psi for a 1 KT	Damage level to be expected
Heavy tanks	55	85	Moderate
	30	50	Light
Scout cars	30	50	Severe
	20	28	Moderate
	12	17	Light
B vehicles	15	21	Severe
	10	14	Moderate
	7	10	Light
Field artillery (in open)	20	28	Severe
	15	21	Moderate
	10	14	Light
Field artillery (in gun pit)	20	28	Light
Heavy mortars	40	75	Moderate
	15	21	Light
Heavy girder bridges (side on)	20	28	Severe
Wireless sets	15	21	Severe
	10	14	Moderate
	3	4	Moderate
4 men fire position—			
LMG embrasure and shelter	30	50	Severe
	18	27	Moderate
	8	13	Light
Main trench	30	50	Severe
Aircraft parked—			
Bomber	5±2	7±2	Depending on aspect
Fighter	12	17	Severe
Aircraft airborne	10±5	14±7	Kill
Men (but remember other accompanying effects)			Injury level to be expected
Men standing in open	8	13	Severe
	5	7	Moderate
	3	4	Light
Men laying in open	12	17	Severe
	9	14	Moderate
	6	8	Light
Men in revetted trenches	20	28	Moderate
	8	13	Light

Damage level criteria for equipment

1. *Light damage.*—Will not interfere seriously with immediate use. Will require some repair to restore to full use.
2. *Moderate damage.*—Requires repair facilities available in field workshops.
3. *Severe damage.*—Requires base repair.

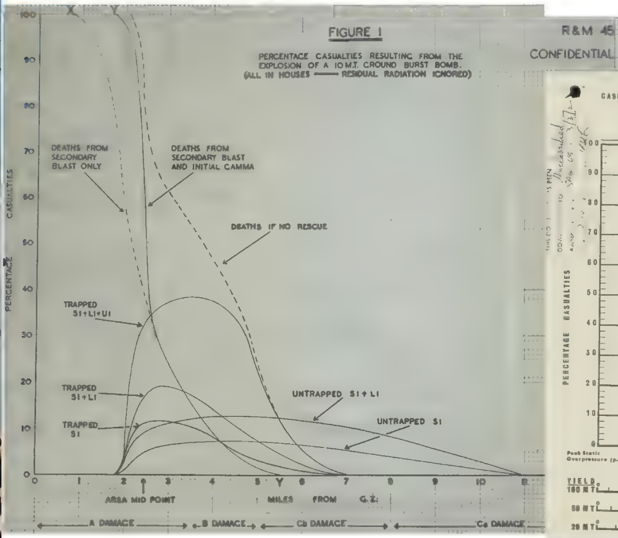
[1] For associated dynamic pressures, *see* Table III.
[2] Normalized for non-desert terrain.

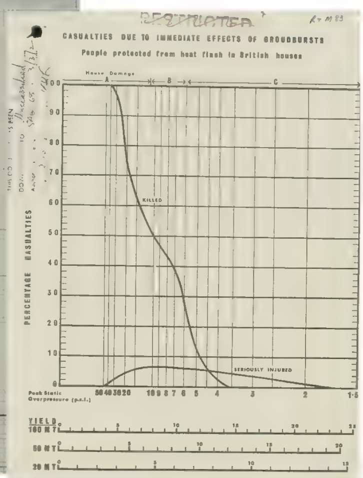


Operation BUFFALO - Round 4.
Crater region dose-rate contours in r/hr at H+1 hour.

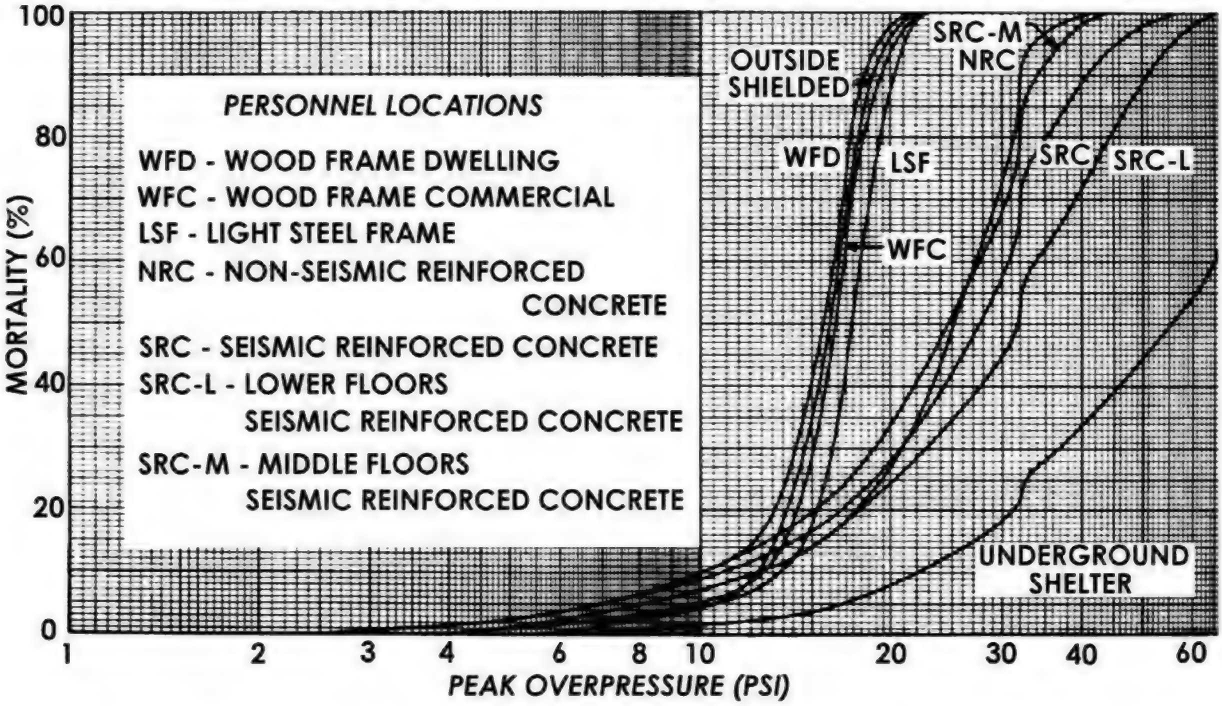
Antler (left) and Buffalo (below) Maralinga nuclear tests

15 kt Buffalo-1 blast on Land Rover car at 600 metres range

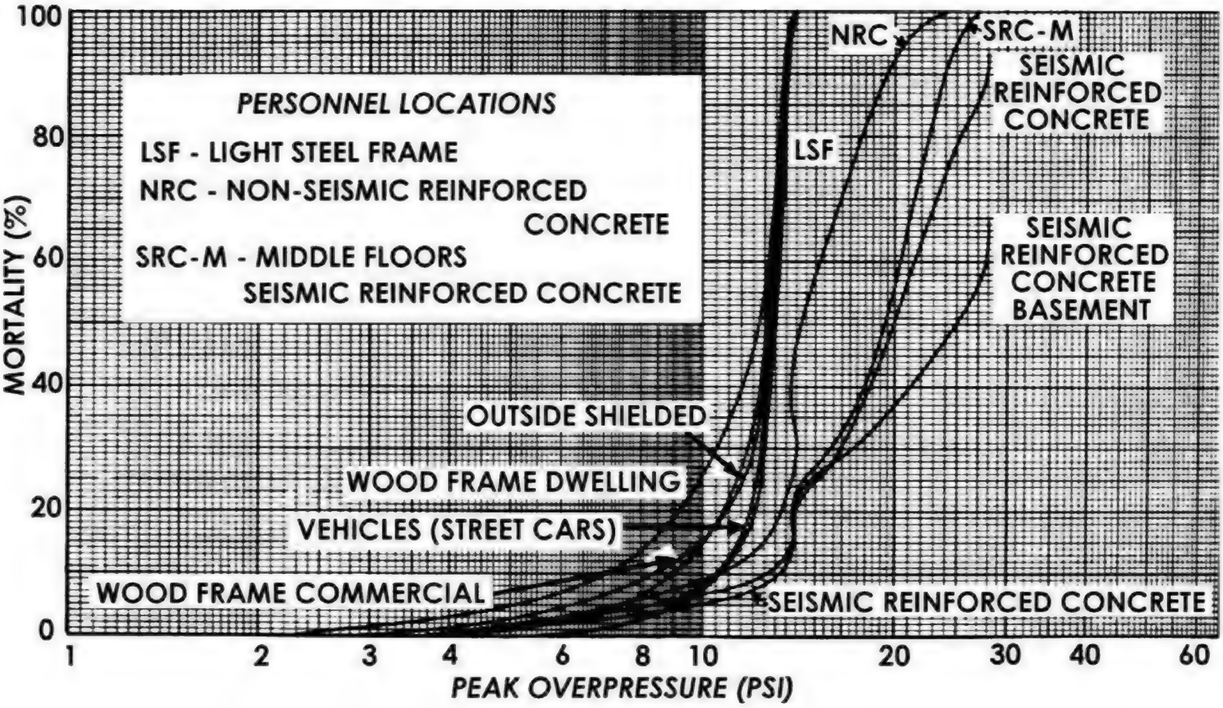




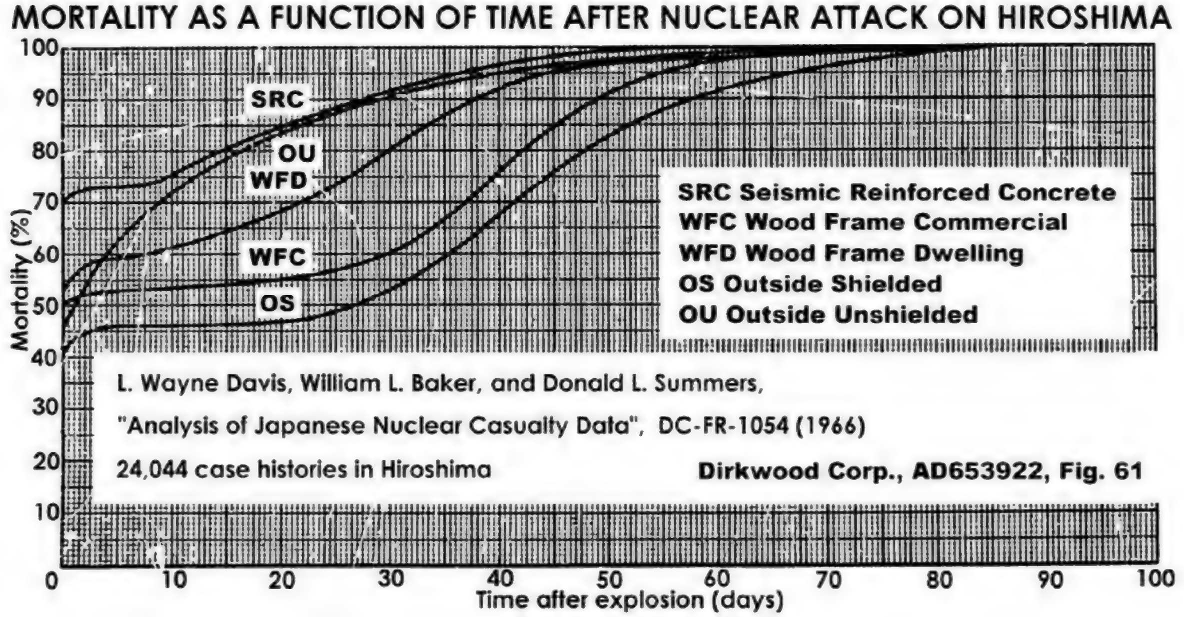
TOTAL MORTALITY VERSUS PEAK OVERPRESSURE IN NAGASAKI



TOTAL MORTALITY VERSUS PEAK OVERPRESSURE IN HIROSHIMA



MORTALITY AS A FUNCTION OF TIME AFTER NUCLEAR ATTACK ON HIROSHIMA



Left: the Dirkwood Corporation analysis of the mortality rates as a function of peak overpressure in Nagasaki and Hiroshima is based on 24,044 traced case histories in Hiroshima and 11,055 in Nagasaki (a total of 35,099 cases). The report by L. Wayne Davis, William L. Baker, and Donald L. Summers, *Analysis of Japanese Casualty Data,* DC-FR-1054, AD653922 (1966), summarises the effects versus distance.

A classified report by L. Wayne Davis, et al., *Prediction of Urban Casualties and the Medical Load from a High-Yield Nuclear Burst,* Dirkwood Corporation paper DC-P-1060 (1968), compares the peak overpressures for the casualties in each city to those from the main Texas City Disaster surface burst explosion of 1947, when 0.67 kt of explosive in a ship detonated after a fire. (This is corrected for the effective explosion energy, which was less than the total mass of explosive involved because some was on a nearby dock and did not explode simultaneously, and some burned without detonating.) Comparison of mortality versus peak overpressure curves for different events shows the influence of nuclear radiation and the firestorm at Hiroshima on total casualty rates.

Radiation risks from nuclear explosions in Hiroshima and Nagasaki were insignificant and smaller than those from natural background cancer rates, except for leukemia in people receiving over 1000 millisieverts (equal to 1 sievert, or 100 rems), where the leukemia death rate was 3.5% of which 2.4% was radiation exposure induced. Natural cancer deaths = 11%.

Dose range milli-sievert	Number in 1950	Cancer deaths (excl. leukaemia)		Leukaemia deaths	
		total rate	rate from radiation	total rate	rate from radiation
Less than 100	68467	11.2%	0.09%	0.2%	0.01%
100 to 200	5949	12.3%	0.7%	0.2%	-0.01%
200 to 1000	9806	13.2%	1.9%	0.6%	0.3%
More than 1000	1829	24.1%	8.1%	3.5%	2.4%
All	**86611**	**11.7%**	**0.6%**	**0.3%**	**0.1%**

Table 1. Cancer deaths among 86611 Hiroshima and Nagasaki survivors, 1950-2000, separated by dose bands [5](Preston et al 2004). The total radiation-related deaths from solid cancer and leukaemia were 480 and 93, respectively. The rates highlighted in green are consistent with zero, statistically.

5 Preston, Dale L. et al (2004) Radiation Research. 162: 377–389. http://www.bioone.org/doi/abs/10.1667/RR3232

In Hiroshima, only 0.9% (17 burns) of 1,881 burns were due to ignited clothing, and only 0.7% (15 burns) were due to burns by firestorm flames!

TABLE 8.3A

Number of Persons with Burns from Different Causes (Tokyo Imperial University's First Survey, October–November 1945)

Distance from Hypocenter (km)	Secondary Burns† From Clothes on Fire	Secondary Burns† By Flame	Total Burns
0.6–1.0	3 (3.3)		89
1.1–1.5		1 (1.1)	327
1.6–2.0	4 (0.5)	4 (1.2)	717
2.1–2.5		6 (0.8)	558
2.6–3.0	5 (0.8)	3 (0.5)	140
3.1–3.5	4 (2.8)	1 (0.7)	41
3.6–4.0	1 (2.4)		4
Total	17 (0.9)	15 (0.7)	1,881

* Primary burns are burns by thermal rays from the A-bomb.
† Secondary burns are burns by fire other than thermal rays.
‡ Figures in parentheses are percentages of incidence.
Source: T. Kajitani and S. Hatano, "Medical survey on acute effects of atomic bomb in Hiroshima," in CRIABC vol. I, p. 522.

Note: there were 5 burns cases within 0.6 km, all primary

TABLE 8.3B

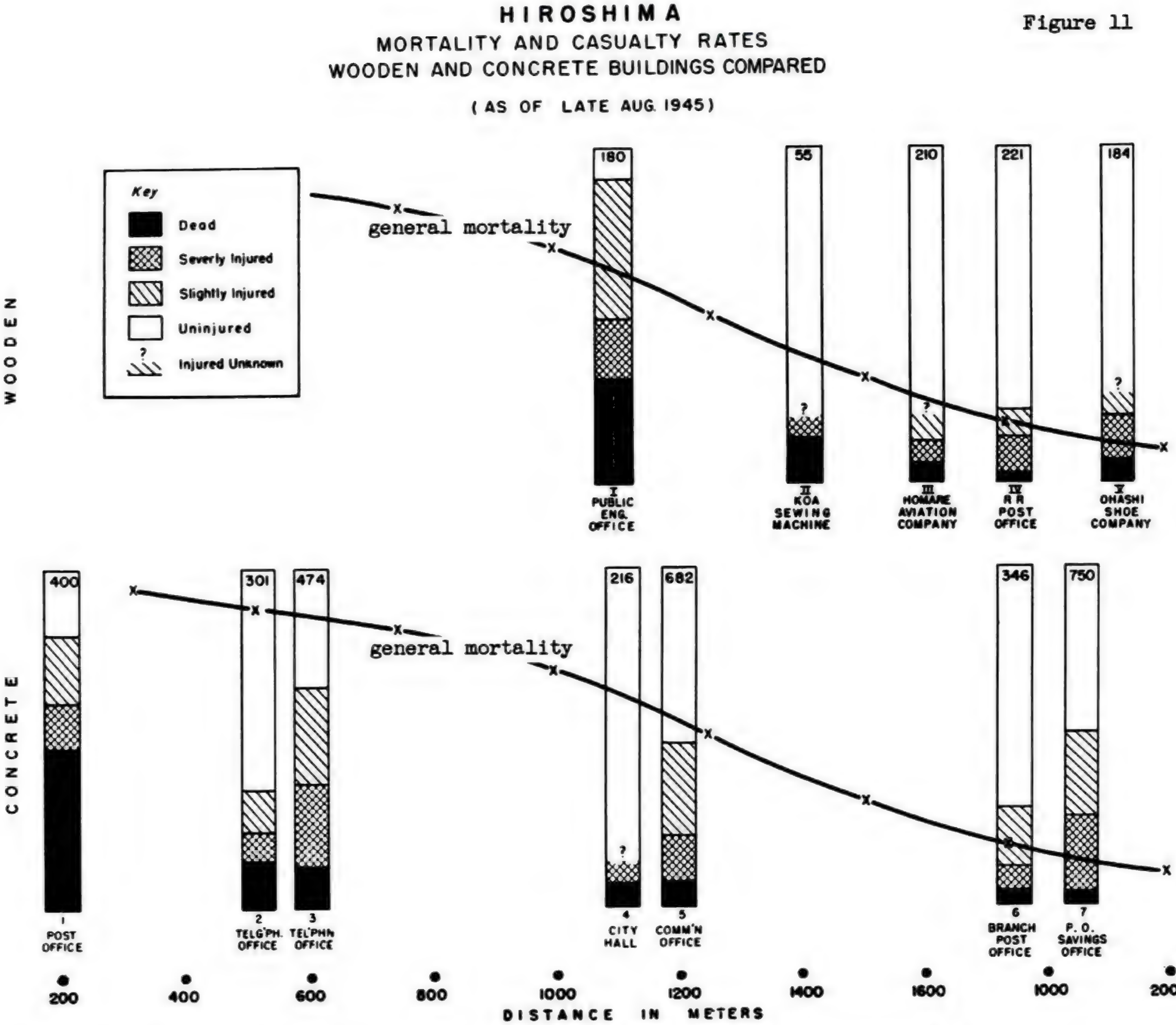
Region of Burns

	Head		Face		Neck		Total	
	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors
Number of persons	179 (11.7)*	44 (12.3)	1,030 (67.4)	127 (35.7)	643 (42.1)	78 (21.9)	1,526	355
Total	223 (11.8)		1,157 (61.5)		721 (38.3)		1,881	

* Figures in parentheses are percentages of incidence.
Source: T. Kajitani and S. Hatano, "Medical survey on acute effects of atomic bomb in Hiroshima," in CRIABC vol. I, p. 522.

Above: extract from "Hiroshima and Nagasaki: The Physical, Social and Medical Effects", 1981 by the Japanese Committee for the Compilation of Materials on Damage Caused by Atomic Bombs

Hiroshima



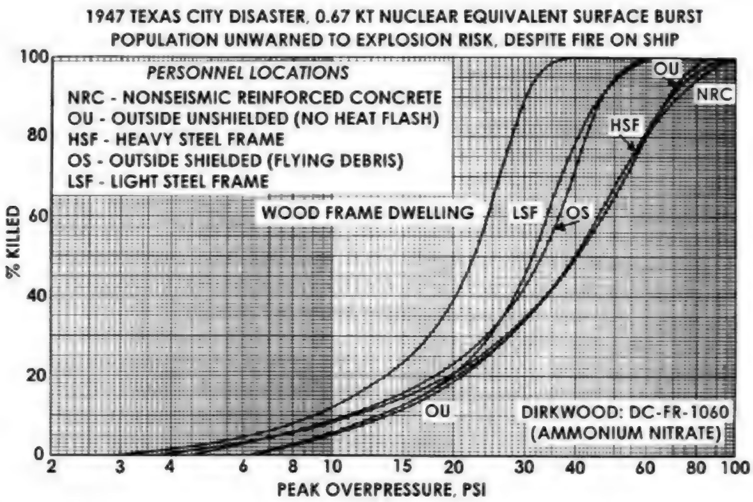
Above: Fig. 12 from Ashley W. Oughterson, et al., *Medical Effects of Atomic Bombs: The Report of the Joint Commission for the Investigation of the Effects of the Atomic Bomb in Japan,* Volume VI, U. S. Army Institute of Pathology, NP-3041, 1951, comparing the overall general mortality for Hiroshima with the mortality inside wooden and concrete buildings. *Hiroshima's obsolete wooden houses had a higher mortality than concrete buildings.*

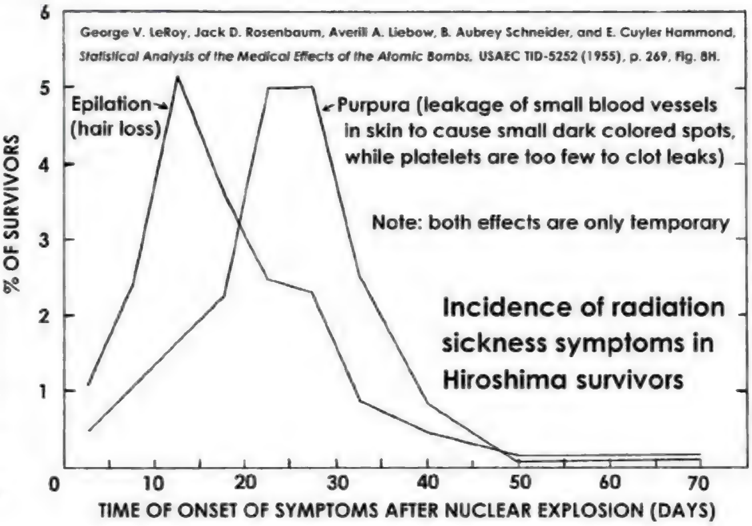
Table 12 of that report is the basis of most of the data in Table 12.21 on page 547 of the 3rd edition (1977) of Glasstone and Dolan's book, *Effects of Nuclear Weapons,* which averages Hiroshima survival data for concrete buildings and correlates it to "degrees of damage," not distance. *This correlation can be deceptive, because some casualties in concrete buildings were not due to blast effects, but due to nuclear radiation, which predominated on the upper floors, where there was less shielding from the air burst overhead than for the lower floors.* Most fire damage to these buildings occurred 2-3 hours later at the height of the firestorm, by which time most survivors had evacuated, so *the fire damage in concrete buildings did not determine casualty rates* (e.g., 207 out of 400 people *survived* in Hiroshima's Post Office, burned-out just 200 metres from ground zero).

Glasstone and Dolan's Table 12.21 correlates "severe damage" to 88% killed in the two reinforced concrete buildings right next to ground zero in Hiroshima.

To correlate "moderate damage" to 14% mortality (106 killed out of 775 people), Glasstone and Dolan average NP-3041's Table 12 data for Hiroshima's Telegraph Office at 500 metres (301 occupants, 45 killed) and the Central Telephone Office at 600 metres (474 occupants, 61 killed). Glasstone and Dolan's correlation of "light damage" to 8% killed is NP-3041's Table 12 for Hiroshima City Hall at 1.1 km (216 occupants, 18 died up to 10 November 1945) and the Communications Office at 1.2 km (682 occupants, 56 killed). *These data only apply to an unwarned population inside concrete buildings.*

Hiroshima





Above: casualty risks in the unwarned population from blast effects in typical kinds of American city building were firmly established after the 16 April 1947 Texas City Disaster. Because the thermal effects were trivial, people in the open were safer than those behind objects, due to the flying debris. Acute radiation syndrome affected fewer than 5% of the survivors of Hiroshima.

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DEPARTMENT OF THE ARMY TECHNICAL MANUAL	TM 23-200
DEPARTMENT OF THE NAVY	OPNAV INSTRUCTION 03400.1B
DEPARTMENT OF THE AIR FORCE	AFL 136-1
MARINE CORPS PUBLICATIONS	NAVMC 1104 REV

CAPABILITIES

OF

ATOMIC WEAPONS (U)

Prepared by
Armed Forces Special Weapons Project

DEPARTMENTS OF THE ARMY, THE NAVY
AND THE AIR FORCE

REVISED EDITION NOVEMBER 1957

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FIGURE 5-2

~~CONFIDENTIAL~~

	1 KT	100 KT (cal/cm²)	10 MT
Thermal effects:			
Second degree bare skin burn..	4	5.1	9.1

~~CONFIDENTIAL~~

Table 6–2. Critical Radiant Exposures for Burns Under Clothing

(Expressed in cal/cm² incident on outer surface of cloth)

Clothing	Burn	1 KT	100 KT	10 MT
Summer Uniform..........	1°	8	11	14
(2 layers)..............	2°	20	25	35
Winter Uniform..........	1°	60	80	100
(4 layers)..............	2°	70	90	120

Note. These values are sensitively dependent upon many variables which are not easily defined (see text), and are probably correct within a factor of two.

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Table 6–5. Dose Transmission Factors (Interior Dose/Exterior Dose)

Geometry	Gamma rays: Initial	Gamma rays: Residual	Neutrons
Foxholes [b]........................	0.05–0.10	0.02–0.10	0.3

[b] No line-of-sight radiation received.

"A few secondary burns resulted from primary flaming of clothing but many people reported such instances in which they were able to beat the fires out without sustaining burns of the underlying skin." - U. S. Strategic Bombing Survey, Medical Division, *The Effects of Atomic Bombs on Health and Medical Services in Hiroshima and Nagasaki*, March 1947, page 25.

Right: flash burns *only occurred in an unobstructed radial line from the fireball,* giving window area burns to chairs at 1 mile in Hiroshima, and fence "shadows" on scorched poles at 1.17 mile from ground zero in Nagasaki.

Hiroshima

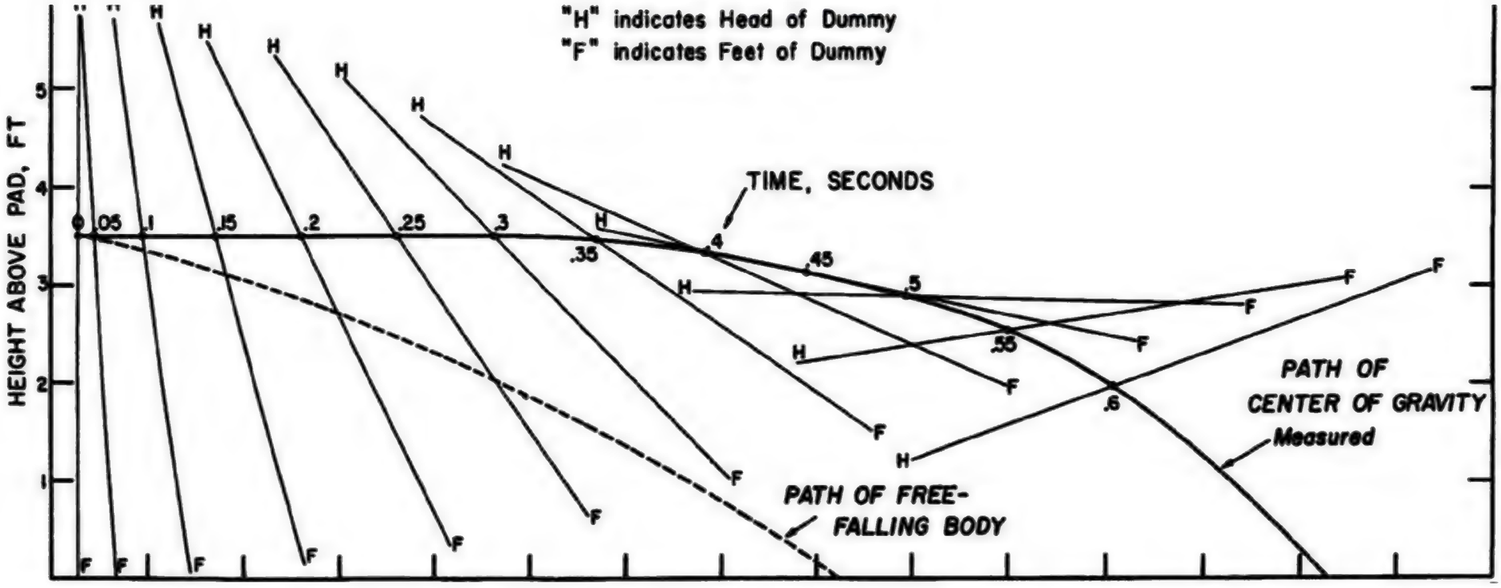
Right: very limited burn areas, under the dark patterns of a tight, single-layer Kimono dress, Hiroshima. Figs. 28 and 29 in Dirkwood Corp. report DC-FR-1054 show that the average unshielded lightly clothed person outdoors in Nagasaki had 2nd to 3rd degree (blistering to charring) burns to 20% of the body area at 1.86 km, killing 10%. At 1.37 km, the stronger flash heated clothing more, and 2nd to 3rd degree flash burns occurred to an average of 38% of body area for personnel unshielded outdoors, killing 50%. The U. S. Strategic Bombing Survey's Medical Division report, *The Effects of Atomic Bombs on Health and Medical Services in Hiroshima and Nagasaki* (March 1947) explains these facts about burns victims:

Pages 24-27: "The fires particularly in Hiroshima apparently built up more slowly than has been encountered in cities that were subjected to heavy incendiary raids. This gave persons more time to escape from the damaged or demolished buildings. ... A few secondary burns resulted from primary flaming of clothing but many people reported such instances in which they were able to beat the fires out without sustaining burns of the underlying skin. ... Generally speaking, the thicker the clothing was the more likely it was to give complete protection against flash burns. ... There were many instances where skin was burned beneath tightly fitted clothing, but was unburned beneath loosely fitted portions."

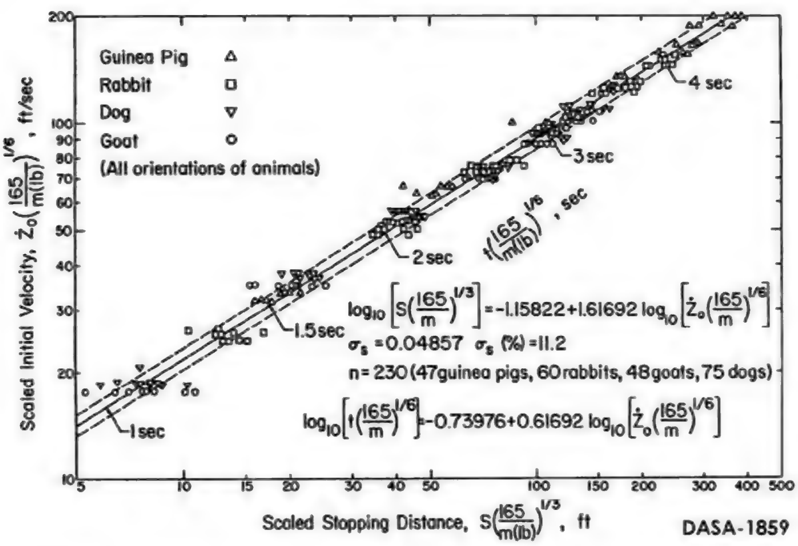
Page 43: "The Joint Commission studied a group of 580 workmen in Hiroshima who were marching across the Koi Bridge facing the bomb at a distance of 7,500 feet. All were burned with the exception of three at the rear who were protected by the eaves of a building." The British Mission to Japan report, *The Effects of the Atomic Bombs at Hiroshima and Nagasaki*, 1946, discusses that group of workmen on page 13, stating that 9 out of the 580 (1.55%) were killed by the serious flash burns at that distance (2.3 km).

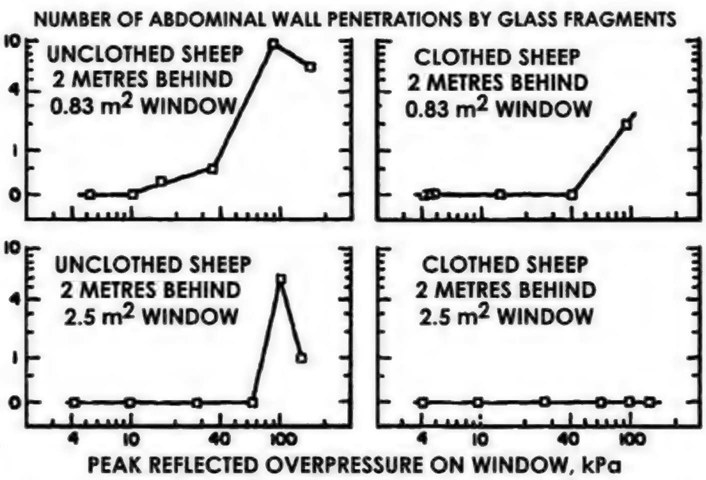
Above: U. S. Strategic Bombing Survey report photos of profile burns to a Hiroshima soldier, illustrating protection afforded against thermal flash burns by a cap and shirt at 1.98 km (1.23 miles) from ground zero. The unburned area below the neck region was covered by clothing. Flash ignited clothing was beaten out and rolled out, unlike the contrived false "examples" of *gasoline-soaked peacetime automobile accident burns*, used by civil defence "critic" liars to supposedly "disprove" civil defense.

Hiroshima



Above: in blast displacements the head impacts the ground *vertically*, it does not hit an obstruction at the peak horizontal velocity. The significance of this fact is that the overall effect is like a fall, albeit taking much longer than gravitation takes because of the hydrodynamic aerofoil lift (where the back is sloping into the blast wind for the first 0.5 second, like an aerofoil). The extra half second of aerodynamic lift gives sufficientreaction time for people to us their arms to protect their heads from the vertical impact. This explains the high survival rate in the Mach stem region at Hiroshima.





Source: DNA-5593T (ADA105824), 1980, Fig. 17. (1 PSI = 6.9 kPa.)

Above: the tumbling distances from blast displacement and the protective quality of clothing in preventing most serious injuries from flying glass fragments are established from experiments on animals. At the 400 kt 12 August 1953 Russian nuclear test, 100% (all 6 animals) exposed outdoors on open ground to 8-10 cal/cm^2 *survived all the effects,* and only 11% (3 of 27) were killed outdoors at 15-26 cal/cm^2 (13 of the 27 had radiation sickness): DTRA-TR-07-38.

Relation Between Overpressure and Missile Parameters

Max pressure psi	Type of missile	Velocity ft/sec geometric mean	Velocity ft/sec range	Mass, gms geometric mean	Mass, gms range	Max missile density No/sq ft
1.9	Window glass	108	50-178	1.45	0.03-10	0.4
3.8	Window glass	168	60-310	0.58	0.01-10	159
5.0	Window glass	170	50-400	0.13	0.002-140	388

Above: Dr Clayton S. White's nuclear test data in his June 1959 testimony to U. S. Congressional hearings on *The Biological and Environmental Effects of Nuclear War,* page 331. Iincreasing the peak overpressure of the blast wave has a small effect on the mean speed of glass fragments, *but causes a larger fall in their mean mass,* because the blast breaks the window up into a very fine "powder" at higher overpressures. *Smaller fragments have less momentum and less penetrating power at very high overpressures, and can be easily stopped by clothing or even the skin surface.* White testified on page 330: "a 10 gram glass fragment, having a velocity of 115 ft/sec has only a 1 percent probability of traversing the abdominal wall ... clothing will degrade the velocity..." Report DASA-1341 calculates a maximum distance for skin lacerations by 50 ft/sec, 10 gram flying glass fragments (acceleration coefficient 0.72 sq. ft/lb) of 7 miles from a 1 Mt surface burst. "At 25 degrees from the edge of a window pane, the density of glass fragments is approximately one-tenth the density of fragments measured directly behind the window." - M. K. Drake, et al., *Collateral Damage,* Science Applications, Inc., Defense Nuclear Agency report DNA 4734Z (ADA071371), 1978, page 5-86.

Vol. 32. No. 8 PICTURE POST August 24, 1946

HOW MAN COMES BACK TO HIROSHIMA: *New Homes Arise in the Bomb Devastation*

The first atom bomb to be dropped in anger fell on Hiroshima on August 6 last year. The death and destruction caused was greater than any that had happened in any other single moment of time. But already a new Hiroshima is rising. Colonies of wooden hutment houses are being built to house the homeless.

AFTER THE ATOM BOMB: AN ASTONISHING REBIRTH

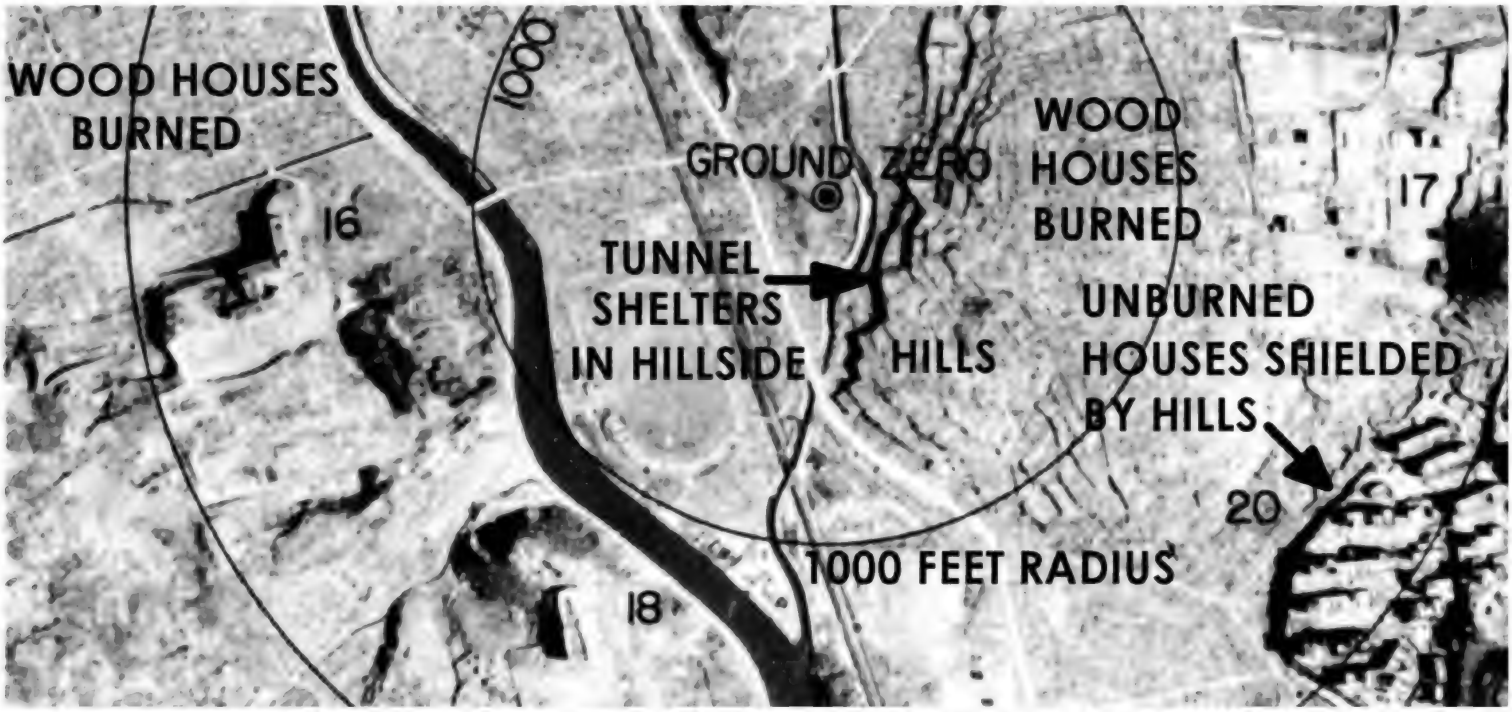
The atom bomb lives up to all expectations in its immediate destructiveness. The scientists' predictions of the after effects of its explosion, however, have been dismally—or perhaps hopefully—wide of the mark.

WHAT would happen to Hiroshima and Nagasaki on the days when the atom bombs dropped was not a matter for speculation. The diabolical thing had been tried out; the range and completeness of its destructive powers were known. Most people's hatred of the idea of indiscriminate slaughter was assuaged by a hope that in a few seconds of time the new form of warfare would end the war and prevent months of prolonged struggle. Hiroshima and Nagasaki suffered wounds which were mortal to the Japanese Empire. That much was expected, that much achieved.

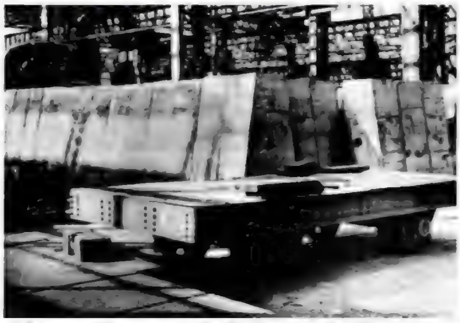
On the long-term effects of the radioactivity released, the scientists had a field day of speculation. With various degrees of certainty they predicted that all life—animal and vegetable—would be impossible for many years on the scorched and acrid desert left by the explosions. Their predictions have proved false. They underestimated the resistance of both Man and Nature. The houses rise again in the two bombed cities. The earth, which was expected to become sterile, now blossoms and bears fruit. Does this mean that we had been unduly terrified by the prospects of atomic warfare? Not at all. The killing and the maiming of the population of whole cities will be as extensive as ever the scientists calculated. Some kinds of civilisation may perish if ever the bomb is used again in full-scale war. But results so far seen show very definitely that the world will survive. Odd men will crawl out of spectacular immunity to build again, as best they know how, and food and flowers will defy all science's efforts at destruction. The atom bomb is not the Last Weapon after all. That may or may not be a source of consolation.

HOW NATURE COMES BACK TO NAGASAKI

In the shadow of wreckage caused by the second atom bomb, crops thrive in the hutment gardens in denial of the scientists' predictions that growth would be impossible for many years.



Above: Nagasaki before and after the 9 August 1945 nuclear attack. Buildings 16 and 18 are surviving but damaged Shiroyama and Chinzei schools, respectively, 500 metres west and south west of ground zero. In 1990, R. L. Stohler of Kaman Sciences Corp. used data on case histories of students on different floors inside these two Nagasaki schools to determine the 50% lethal dose (LD50) of initial nuclear radiation, including blast and thermal burn synergisms: the LD50 is 412 cGy in air/295 cGy in the bone marrow for casualties with either nuclear radiation plus blast injury or only nuclear radiation, and 397 cGy in air/279 cGy in bone marrow for nuclear radiation in combination with thermal burns (report DNA-TR-87-173, ADA219691). This synergism is due to the later infection of wounds, which was worse in Hiroshima's hospitals than in Nagasaki's. Hills "shielded" the south east homes from firebrands.



Above: Nagasaki's "blast walls," made of pre-cast concrete (left) and earth-filled wooden planks (right). The idea of a blast wall is to shield flying debris and hurricane-strength blast winds. The blast wall base is wider than the top, to prevent overturning for the blast load design specification. These simple blast walls protected machinery at 0.85 mile from ground zero, Nagasaki. The photographs of simple and effective protection were published in Figure 12.37 of the June 1957 edition of *The Effects of Nuclear Weapons*, but were not included in later editions.

Above: a typical multistorey steel-frame building surviving structurally intact at 0.85 mile from ground zero in Nagasaki. The surrounding wooden buildings collapsed and were burned by fires.

LA-14066-H
History

Tracing the Origins of the W76: 1966–Spring 1973 (U)

Betty L. Perkins

November 3, 2003

7. Yield: The Confetti Argument

Agnew felt that the yield of the W68 was too low to be really effective. In addition, in terms of the overall total yield available from all the W68 warheads, the W68 design was very costly in terms of the amount of required special nuclear materials.

In an April 1972 TWX to Assistant Director for Safety and Liaison (Division of Military Application) Colonel Robert T. Duff, Agnew reported that he was worried about maintaining the U.S. nuclear deterrent. Agnew noted, "It occurs to me that as we go to lower and lower yields in our strategic missile warheads and the Soviet Union builds up a better and better civil defense position, the reality of this deterrent may become questionable.

(b)(3)

If the Soviet leadership believes this, then our strategic deterrent will have lost a good deal of its force. If our MIRV trend continues we'll be threatening to throw confetti at a potential aggressor. Confetti has high penetration and survivability but little deterrent power."[281]

In a letter dated October 10, 1972, to Giller, at that time Assistant General Manager for National Security, Agnew again noted several reasons why low yield warheads might not be the best solution for maximizing the deterrence capability of the stockpile. He reported that considering the number of required submarines and the low efficiency in their use of special nuclear material, the low-yield warheads were not very cost effective. Moreover, Agnew pointed out that for the Hiroshima device, the effects on Hiroshima in terms of loss of substantial buildings and the people in them "wasn't all that impressive." In terms of loss of life, the USSR had lost more than ten million people in WWII. Although the Soviets had an extensive civil-defense network in place, even if that did not work to reduce loss of civilian lives, the Soviets might not mind losing a few people. Agnew wrote, "Again, to me, to continue to increase warhead numbers at the cost of a decrease in yield per warhead could eventually lead to no deterrence in the minds of those we hope to deter." Agnew stated, "I feel very strongly that we should endeavor to convince the DoD that what they should have on the next round is a mix of yields.

[281] H. M. Agnew, University of California, Los Alamos Scientific Laboratory, Los Alamos, N.M. to BY3/Colonel Robert T. Duff, USAF, Assistant Director for Safety and Liaison, Division of Military Application USAEC, Wash., D.C. (SRD) (April 14, 1972), pp. 1–2, B11, Drawer 56, Folder 1 of 4.

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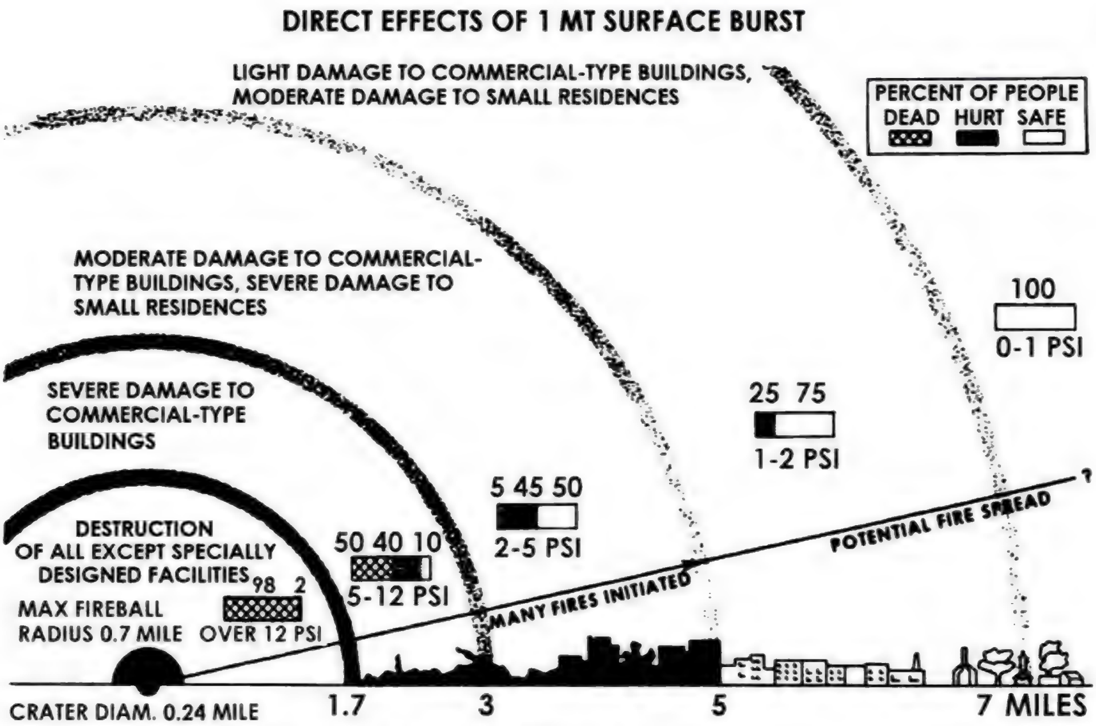
Hiroshima



Left: the 1973 U. S. Department of Defense *DCPA Attack Environment Manual* provided this casualty-versus-peak overpressure analysis, associating the 5-12 psi peak overpressure zone with 50 mortality, without source references. It was used to for *grossly deceptive exaggeration, ignoring civil defence effectiveness* by the 1979 U. S. Office of Technology Assessment study, *The Effects of Nuclear War.* Deceptions were excluded from public scrutiny, debate and analysis by deliberately assigning reports secret and/or "limited distribution" (ostensibly to keep it from Moscow).

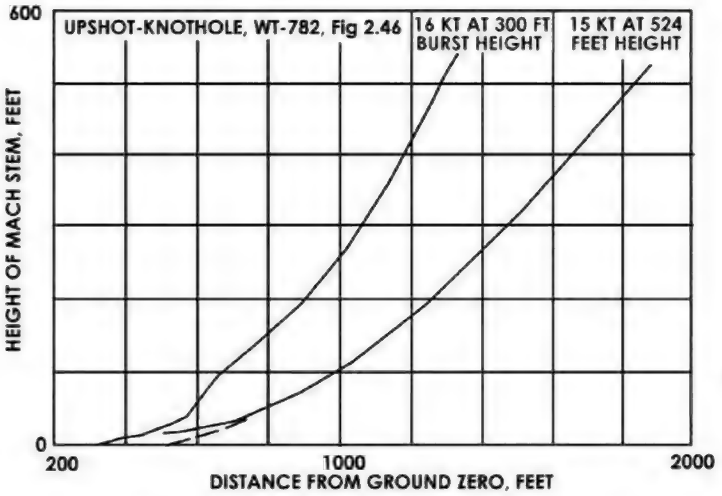
BANK OF JAPAN, HIROSHIMA (BUILDING 24)

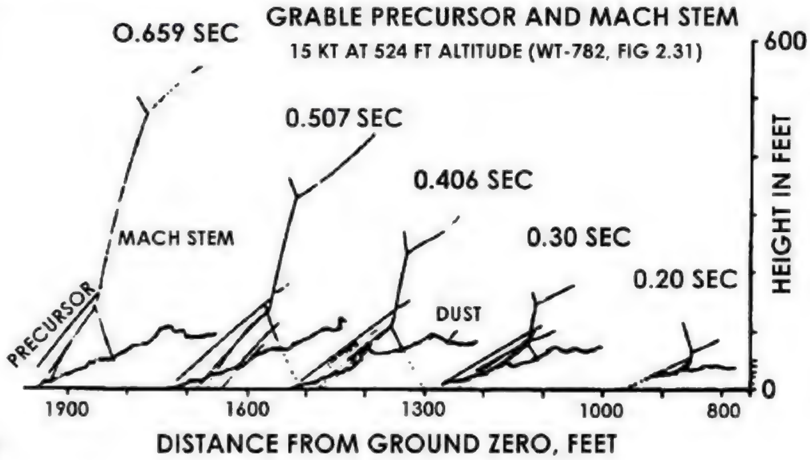
Left: 50% of 100 people survived inside the concrete Bank of Japan (building 24 in Hiroshima, in the U. S. Strategic Bombing Survey report) at a peak overpressure of 18 psi, just 390 metres from ground zero in Hiroshima. This was well inside the "firestorm" area, and only 7.5 m from the nearest burning building. A second floor fire, due to a firebrand blown through a broken window, was extinguished by the survivors using water fire buckets at 1.5 hours after the nuclear explosion. Note 3rd floor windows soot.

The evacuated 3rd floor suffered a firebrand ignition, which was discovered too late to extinguish, and burned *without spreading to lower floors.* (Source: *DCPA Attack Environment Manual,* Chapter 3, Panel 26, 1973. The U. S. Strategic Bombing Survey report shows that it had 12 inch thick reinforced concrete walls and 20 inches of sand on the roof.)

GEIBI BANK COMPANY, HIROSHIMA (BUILDING 18)

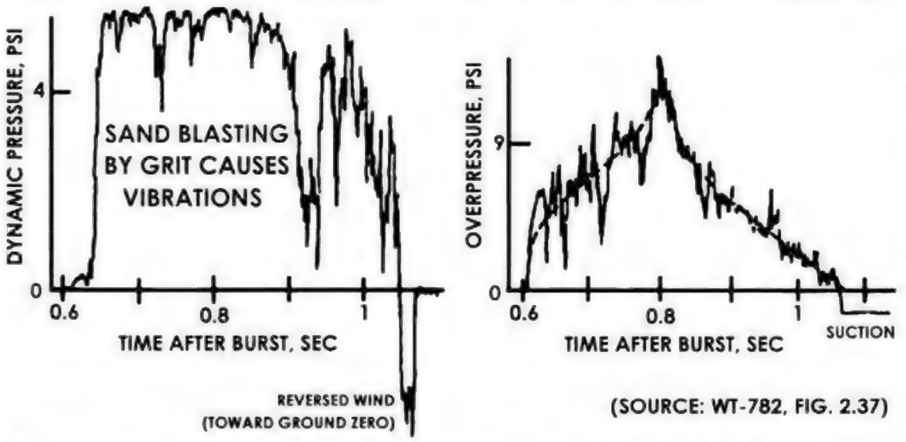
Left: the Geibi Bank building (building 18) after it survived 8 psi peak overpressure at 293 metres from ground zero in Hiroshima, again inside the "firestorm" area. It survived fire completely; firebrands blown in through first and third floor broken windows at 2.25 hours after the explosion ignited curtains and furniture but these fires were extinguished by survivors using water fire buckets. (The U. S. Strategic Bombing Survey reported it had 10 inch reinforced concrete walls.)



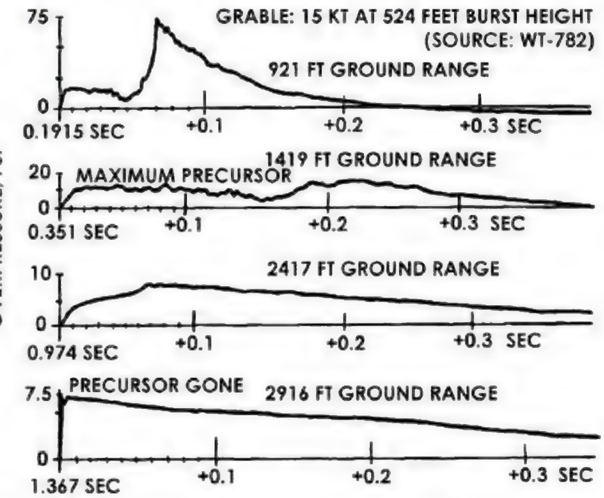


Above: the Mach stem height and precursor height are vitally important in air bursts, because *these phenomena only occur over a certain range of heights in an air burst*. Increasing the height of burst *considerably reduces the Mach stem height at a fixed distance*. If the height of the Mach stem is lower than the building it encounters, only the floors *below* the Mach stem height will be subject to a single, horizontally-moving shock wave, and higher floors will experience *two* shock waves. In the latter case, the *direct* wave comes radially (on a downward slant) from the detonation point, but the *ground-reflected* shock wave comes on an *upward* slant from a mirror point one burst height *below* ground. These non-horizontal angles of incidence reduces the *horizontal* wind or dynamic pressure component, as compared to the Mach wave. The vertical wind does not blow things sideways.

DYNAMIC AND OVERPRESSURE PRECURSOR BLAST WAVEFORMS
2000 FEET FROM GROUND ZERO, GRABLE, NEVADA (15 KT 524 FT AIR BURST)



MEASUREMENTS AT 10 FEET HEIGHT (PRECURSOR WAS SLIGHTLY WEAKER AT 40 FEET HEIGHT)



MAIN SHOCK WAVE OVERTAKING PRECURSOR AT 2417-2916 FT

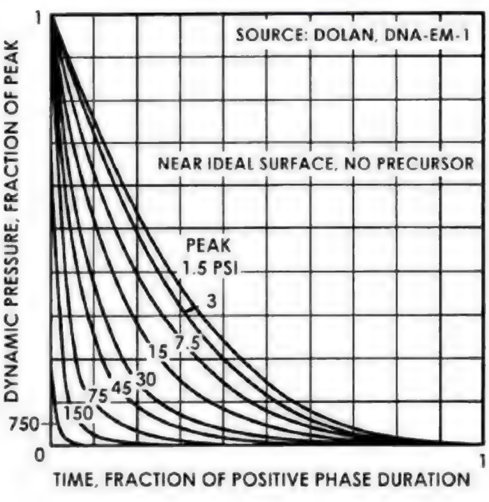
Above: the most important effects of the precursor on overpressure and dynamic pressure are *changes in the waveform shape*, not the change in the peak pressure. Examples are shown for the 1953 *Grable* test, a 15 kt burst detonated at a height of 524 feet over Nevada desert sand. The waveforms for both overpressure and dynamic pressure at 1,419-2,000 feet are completely dominated by the precursor "sandstorm," with jagged fluctuations due to pressure sensor vibrations from impacts of dust, sand, grit, and small stones during sandblasting. At 2,000 feet (*above left*), the dynamic pressure *remains near its peak value for most of the positive phase*, instead of falling rapidly after a spiked peak, which occurs when no precursor is present (*compare the graphs above to "ideal" blast waveforms, below*). Consequently, the dynamic pressure *impulse* (dynamic pressure integrated over time) is greatly increased in a precursor for a given fixed peak pressure.

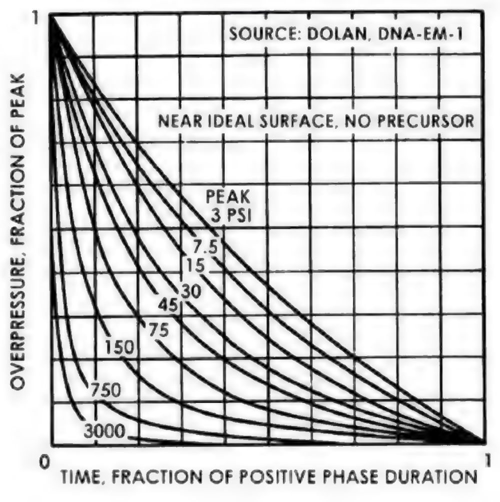
An example of the role of the precursor's dynamic pressure impulse in damaging wind drag-sensitive targets is the effect of the *Grable* precursor on World War II jeeps. On the previous test, *Encore*, where there was no precursor, jeeps were rolled up to 11 metres and moderately damaged. But for a similar peak overpressure, the precursor of *Grable* caused severe damage or the complete destruction of jeeps, with chassis, engine and wheel debris blown for distances of over 300 m (ref.: DNA-5826F, p. 2).

Right: the "ideal" overpressure at time t after blast arrival in a free air burst is

$$p_t \approx p(1 - t/t_p^{+})/(1 + 0.1pt/t_p^{+}),$$

where p is the peak overpressure in psi, and t_p^{+} is the overpressure (positive phase) duration. The "ideal" dynamic pressure q_t falls even faster with time: $q \approx 2.5p^2/(p + 7P_0)$, where P_0 is ambient atmospheric pressure.



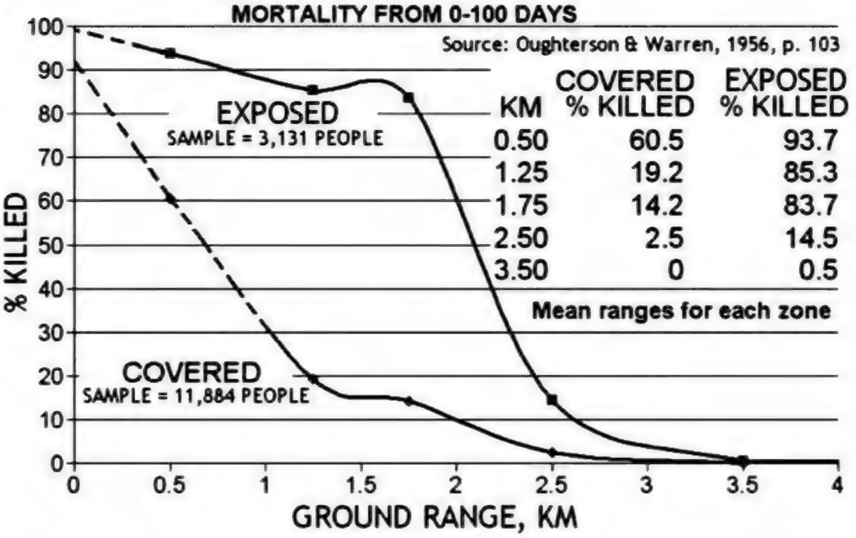


Hiroshima

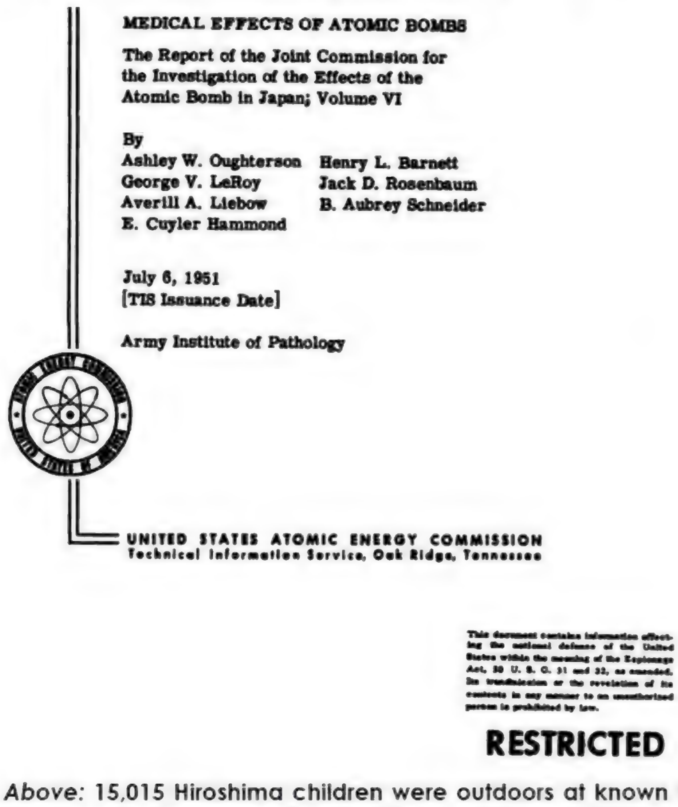
For a month before the Hiroshima and Nagasaki nuclear attacks on 6 and 9 of August 1945, weather aircraft were sent over the cities daily to "accustom the Japanese to seeing daytime flights of two or three bombers" (*The Tibbets Story*, the autobiography of 509th nuclear bombing group commander, Hiroshima pilot Colonel Paul Tibbets). B-29 weather aircraft preceded the nuclear B-29 bomber. In Hiroshima the air-raid warning sounded at 7 am, and the all-clear at 7:30 am, but the bomb was dropped at 8:09 am. Thousands cooked breakfasts on charcoal braziers in wooden homes. In Nagasaki, the air-raid sounded at 7:50 am but was cleared before the bomb fell.

The secret May 1947 U. S. Strategic Bombing Survey report 92 on Hiroshima reveals the facts on pages 4-6: "Six persons who had been in reinforced-concrete buildings within 3,200 feet [975 m] of air zero stated that black cotton black-out curtains were ignited by flash heat. ... A large proportion of over 1,000 persons questioned was, however, in agreement that a great majority of the original fires were started by debris falling on kitchen charcoal fires. ... There had been practically no rain in the city for about 3 weeks. ... There were no automatic sprinkler systems in building. ..."

The secret June 1947 U. S. Strategic Bombing Survey report 93 on Nagasaki states (v. 1, p. 10): "... the raid alarm was not given ... until 7 minutes after the atomic bomb ... less than 400 persons were in the tunnel shelters which had capacities totalling approximately 70,000."



Above: data on survival for 15,015 Hiroshima work party children, from Dr Ashley Oughterson and Dr Shields Warren's book, *Medical Effects of the Atomic Bomb in Japan* (McGraw-Hill, New York, 1956, page 103). This graph shows that shadowing saved many lives. They noted the fire risk in Hiroshima on page 17: "Conditions in Hiroshima were ideal for a conflagration. Thousands of wooden dwellings and shops were crowded together along narrow streets and were filled with combustible material."



MEDICAL EFFECTS OF ATOMIC BOMBS

The Report of the Joint Commission for the Investigation of the Effects of the Atomic Bomb in Japan; Volume VI

By
Ashley W. Oughterson, George V. LeRoy, Averill A. Liebow, E. Cuyler Hammond, Henry L. Barnett, Jack D. Rosenbaum, B. Aubrey Schneider

July 6, 1951
[TIS Issuance Date]

Army Institute of Pathology

UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service, Oak Ridge, Tennessee

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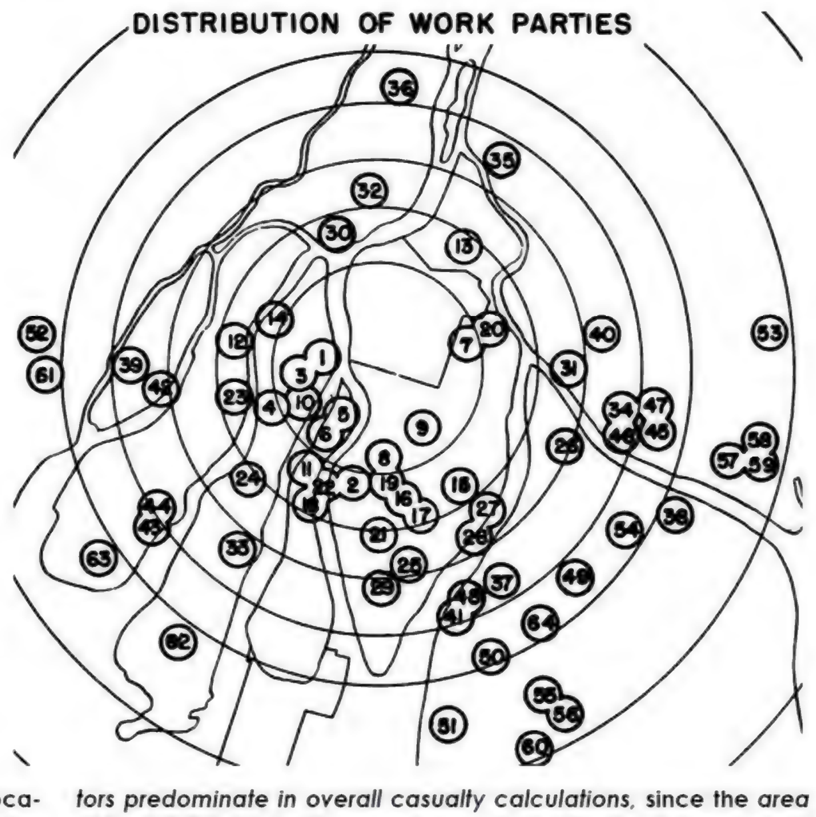


Above: 15,015 Hiroshima children were outdoors at known locations in patriotic work parties at 8:15am on 6 August 1945, clearing firebreak areas in overcrowded wooden housing, to try to prevent a firestorm occurring in anticipated incendiary air-raids. The data below is from Figures 9 and 10 in the report by Ashley W. Oughterson, et al., *Medical Effects of Atomic Bombs: The Report of the Joint Commission for the Investigation of the Effects of the Atomic Bomb in Japan*, Volume VI, U. S. Army Institute of Pathology, NP-3041, 1951.

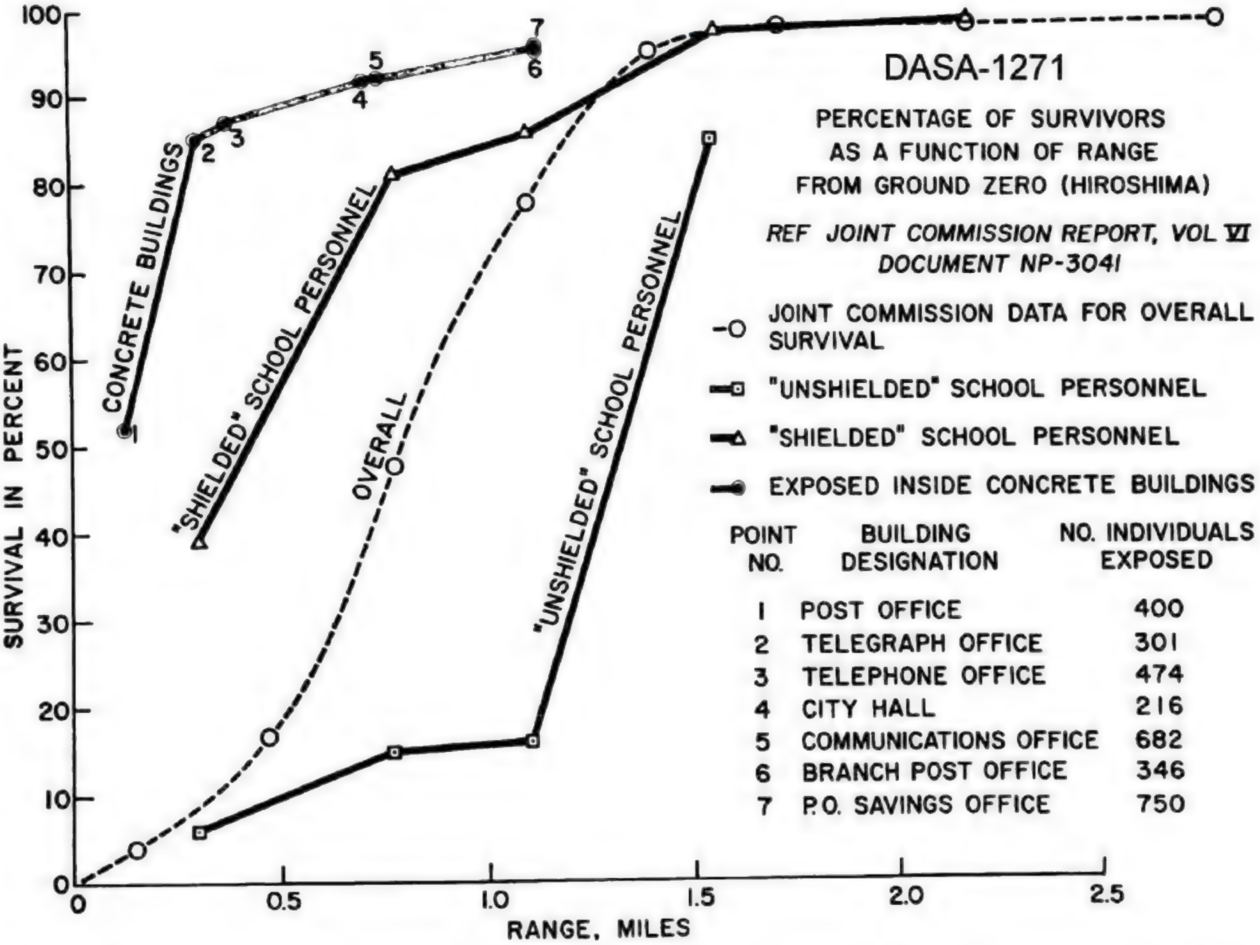
At 0-1, 1-1.5, 1.5-2, and 2-3 km, mortality rates of 93.7, 85.3, 83.7, and 14.5% existed outdoors, but those shielded from the thermal flash had mortality rates of only 60.5, 19.2, 14.2, and 2.5% respectively (*the firestorm developed between 30 minutes to 3 hours after burst, allowing time to escape it*). Hence, shadowing in the four zones at 0-1, 1-1.5, 1.5-2, and 3-4 km gave mortality "protective factors" of 1.55, 4.44, 5.89 and 5.80, respectively. Since *areas are proportional to the square of the radius*, the *higher protection factors predominate in overall casualty calculations*, since the *area* of the 1-1.5 km "shell" zone exceeds that of the 0-1 km zone, and the area of the 1.5-2 km "shell" zone is much larger.

The areas covered between the inner and outer radii limits of each of the four zones (0-1, 1-1.5, 1.5-2, and 3-4 km) is $\pi(a^2 - b^2)$, where a and b are the outer and inner radii of the zone, respectively, giving 3.14, 3.93, 5.50 and 15.7 square kilometres. Thus, if the distribution of the pre-attack population without shielding is uniformly n persons per square kilometre, the number killed outdoors within 3 km is $13.2n$ personnel, compared to just $3.83n$ personnel *for those with shadow protection from the fireball's thermal radiation*. So the overall shadow protective factor *for mortality in randomly distributed people within 3 km of ground zero* in Hiroshima was $13.2n/(3.83n) = 3.44$, reducing the unshielded death risk in Hiroshima to just 29%, for people shadowed from the fireball's thermal radiation flash by a tree, fence, clothing, building, vehicle, bridge, tunnel, or hill.

Hiroshima

U. S. Strategic Bombing Survey, Medical Division, *The Effects of Atomic Bombs on Health and Medical Services in Hiroshima and Nagasaki,* March 1947, page 25:

"A few secondary burns resulted from primary flaming of clothing but many people reported such instances in which they were able to beat the fires out without sustaining burns of the underlying skin."



Dr Clayton S. White, M.D. (DASA-1271, 1961, pp. 32-36):

"The area of [destruction to wooden houses at Hiroshima, was] about 1.2 mile radius, a range at which 4-5 psi existed. At this range there was an overall survival of near 90 percent. ... one must not confuse the area of complete destruction of houses ... with 'complete destruction' of people. …

"The gloomy habit of confusing the two concepts is, I am afraid, as prevalent as it is unrealistic and, indeed, untrue. ... Think of the differences in casualties which might have occurred in Hiroshima had the population just been mostly indoors."

Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons,* U. S. Department of Defense, 3rd ed., 1977, paragraphs 12.14, 12.17, and 12.22, pages 545-7: "The high incidence of flash burns caused by thermal radiation among both fatalities and survivors in Japan was undoubtedly related to the light and scanty clothing being worn, because of the warm summer weather ... If there had been an appreciable cloud cover or haze below the burst point, the thermal radiation would have been attenuated somewhat and the frequency of flash burns would have been much less. Had the weather been cold, fewer people would have been outdoors and they would have been wearing more extensive clothing. Both the number of people and individual skin areas exposed to thermal radiation would then have been greatly reduced, and there would have been fewer casualties from flash burns. ... The death rate in Japan was greatest among individuals who were in the open at the time of the explosions; it was less for persons in residential (wood-frame and plaster) structures and least of all for those in concrete buildings. These facts emphasize the influence of circumstances of exposure on the casualties produced by a nuclear weapon and indicate that shielding of some type can be an important factor in survival. ... Had they been forewarned and knowledgeable about areas of relative hazard and safety, there would probably have been fewer casualties even in structures that were badly damaged."

Right: flash burns *only occurred in an unobstructed radial line from the fireball,* proved by window outline scorches to chairs 1.0 mile from ground zero in Hiroshima, and by the fence "shadows" on scorched poles at 1.17 mile in Nagasaki.

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MINISTRY OF SUPPLY

ARMAMENT RESEARCH ESTABLISHMENT

SYMPOSIUM
ON
THE PHYSICAL EFFECTS OF ATOMIC WEAPONS

PAPER No. 5

Civil Defence Studies

E. Leader-Williams
Home Office
(Office of the Chief Scientific Adviser)

AVIA 65

B.9

A SYMPOSIUM
ON
THE PHYSICAL EFFECTS OF ATOMIC WEAPONS

to be held at
The Royal Institution of Great Britain
21, Albemarle St., W.1.
on
September 27 & 28, 1949

Mr.E.Leader-Williams, B.Sc., A.M.Inst.C.E. Chief Scientific Adviser's Department, Home Office.

Because America kept the casualty rates in different kinds of buildings and shelters at Hiroshima and Nagasaki secret, already by 1949 the UK had used its own WWII data to determine this.

Edward Leader-Williams (co-inventor of Morrison indoor table shelter, with Lord Baker, WWII), Secret *Symposium on the Physical Effects of Atomic Weapons*, paper 5, *Civil Defence Studies*. NOTE: the Morrison shelter was adapted in the 1982 Home Office "Domestic Nuclear Shelters - Technical Guidance" by adding a protected escape tunnel to avoid risk trapping.

SECRET

HOME OFFICE

OFFICE OF THE CHIEF SCIENTIFIC ADVISER

CIVIL DEFENCE STUDIES

A CONTRIBUTION TO THE A.R.E. SYMPOSIUM

Leader-Williams in this Secret paper uses WWII survival data for various types of shelters, in conjunction with city skyline "shadowing" protection against radiation, to determine survival of air raid shelters for protection against nuclear attack.

FIG. 1

Casualties in Morrison Shelters

Category of house damage	Distance estimated by the British Mission to Japan at which this category of house damage would occur from a bomb of the Nagasaki type burst at a height of ⅓ mile	Corresponding distance from a burst at ⅛ mile	Data based on H.E. experience				
			Number of Morrison shelter occupants	Killed	Seriously injured	Lightly injured	Proportion of shelter occupants able to escape unaided
A. Totally destroyed	3000 ft.	2500 ft.	115	7%	10%	14%	40%
B. So badly damaged that demolition necessary	5280 ft.	3900 ft.	22	0	5%	5%	60%
C. Damaged and uninhabitable	7920 ft.	6300 ft.	6	0	0	0	100%

From these data it is possible to define the thickness of protective material, e.g. concrete, to give protection at any defined distance. For example, 2 ft. of concrete gives protection from death from radiation immediately under a bomb burst at the Japanese height. However, when a bomb bursts over a city, particularly if the burst is fairly low as is being assumed for the present study, the shielding of intervening buildings between a shelter and the bomb will help in reducing radiation casualties. In an attempt to assess the quantitative importance of this shielding, a very detailed study was made of a sample area in London. Shelters were assumed to be placed in all

protection from flash burn is provided by even comparatively light materials, curtains, etc., and in the conditions of this study where everyone is assumed to be in houses or shelters, no flash burn casualties have been allowed for.

The high proportion of these delayed deaths among Anderson shelter occupants is, of course, due to the fact that the Anderson shelter, as it stands, does not provide a balanced design against the atomic bomb; it is better against blast than it is against gamma radiation. However, it should be a comparatively simple matter to increase the gamma radiation protection by providing an increased thickness of earth cover, and with this provision the Anderson should be at least as good as the Grade A surface shelter.

which the figures for complete rescue are based, ...

after an atomic incident. The figures do show, however, that even shelters of the Anderson or brick surface type provide a substantial measure of protection against the atomic bomb, reducing both the killed and injured to about ⅓rd of what they would be among people in houses. The strengthened brick surface shelter is even better, reducing the figures to about 1/5th of those for houses.

HO 227/ 7

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1467

Edward Leader-Williams continued research into nuclear war shelters, e.g. this report on dual-use basement/underground garages/car parks (also used in Russia for many shelters)

CD 13231

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HOME OFFICE

SCIENTIFIC ADVISER'S BRANCH

1st Draft

The Adaptation of Basement Garages under New Office Buildings for use as Shelters

by E. Leader-Williams

Introduction

1. At the present time the provision of car parking facilities on the site is a pre-requisite for planning permission for office blocks in the L.C.C. area and it is known that this also applies in Manchester and Liverpool. At least in the central part of the L.C.C. area, where sites are most valuable, the required parking facility is usually provided in the basement of the building, the basis being the provision of one parking space for every 2000 sq. ft. of office space.

It is understood that this garage space is at present being provided under new buildings in the L.C.C. area alone at the rate of 10,000 car spaces per year. This is equivalent to 250,000 shelter spaces per year on the last war basis of a space requirement for dormitory shelter of 10 sq. ft. per person. This space requirement may have to be increased somewhat for a long term occupancy, but it is used in this paper as a basis for cost calculations.

2. The plans of six new or proposed buildings in the West End have been examined and the following general observations apply -

(1) The sizes of the basement garages varied from 55,000 sq. ft. to 9,000 sq. ft. (i.e. 5,500 to 900 occupants on the basis of 10 sq. ft. per person).

(2) Two of the garages were in sub-basements with at least a basement, a ground floor and a roof over the whole garage. The remainder were in basements over portions of which the only cover was the ground floor slab. (In one case there was no cover at all over a small part of the basement garage space.)

(3) Access to the basement garages was normally by ramp, though in one case the car access was by lift. Where ramps were provided the normal

width was about 10 ft. which should permit of the entry of about 250 persons per minute. Use of both the in and out ramp would therefore allow an entry rate of about 500 persons per minute which should be adequate to fill most garage shelters in the assumed warning time of four minutes. Garages with lift access might have to be ruled out for shelter purposes unless they could be occupied in advance of the alert.

Blast protection

3. As they stand without alteration it is considered that basement garages under multi-storey steel or reinforced concrete framed office blocks would provide protection to their occupants from blast pressures up to about 10 p.s.i. (i.e. about four miles from a ground burst 10 Mt bomb). At this pressure the superstructure of the building would be very badly damaged, the panel walls would be blown in and the frame might be distorted, but the ground floor over the basement garage should not collapse. Moreover at this pressure it would not be essential to seal the shelter - American tests in Nevada suggest that the occupants of an unsealed shelter should not be injured at this pressure.

4. If the ground floor slabs over the basement garages were strengthened up to the old Grade A standard of strength but not of thickness (slab designed to carry a superimposed load of 1400 lb/sq. ft. at yield stresses) and the basement were sealed against the entry of blast by the provision of suitable blast doors etc. then it is estimated that the occupants should be safe against a blast pressure of at least 50 p.s.i. (i.e. 2 miles from a ground burst 10 Mt. bomb).

5. On the basis of the above estimates of strength, the relative blast casualties among a population in houses, in unstrengthened basements and in basements strengthened to grade A standard would be in the ratio of 1000 to 600 to 150.

6. It has been estimated (CDJPS(S)(54)5) that the extra cost of providing Grade A protection in the basement of an office building is about

5% of the cost of the building. Modern office buildings cost about 10/- per cubic ft. of space or say £5 per sq. ft. of floor area. The L.C.C. requirement for one car space per 2000 ft. of floor space therefore means that one car space would be provided from each £10,000 worth of building. One car space (250 sq. ft.) equals 25 shelter spaces at 10 sq. ft. per person, so that 25 shelter spaces would be provided for each £10,000 worth of building. If the provision of Grade A requirements costs 5% of the cost of the building, the structural provision for each shelter space would therefore cost £20.

Fall-out Protection

7. The two sub-basement garages referred to in paragraph 2 would have a protective factor exceeding 1000 over their whole area. The remaining basements would have a protective factor of more than 1000 over most of their area, but those portions which only had a ground floor slab overhead would be unlikely to have a protective factor exceeding 50. This wide discrepancy is clearly most undesirable in a fall-out refuge. One method of overcoming it, which is being advocated by the U.S. Authorities in the surveys of potential fall-out refuge which they are undertaking, would be by lines painted on the floor to indicate to the occupants which portions of the garage should, and which should not, be used as refuge. Alternatively walls could be constructed to shut off those portions of the basement not suitable for shelter though this could probably not be done without interfering with the peace time use of the garage.

8. If it is required to achieve a protective factor of 200 over the whole basement the ground floor slab would have to be thickened over those portions where it formed the only cover over the basement. For this a slab thickness of about 15 inches would be required to give a protective factor of 200 and the extra cost of this, as compared with the normal slab of about 6 inches thickness, should not exceed about 7/6d. per sq. ft. or say £4 per shelter occupant of those areas where roof thickening is required or £6 per occupant for P.F. of 1000.

9. The provision of a 50 p.s.i. (Grade A) slab over the basement would ensure a protective factor of at least 200 over the whole basement.

Protection from other Hazards

10. Fire. It is not considered likely that a fire storm, such as the one which caused so many casualties among the occupants of basement shelters in Hamburg, would result from a nuclear attack on a British city. Individual buildings, and whole blocks, would certainly be destroyed but modern office buildings of the type under consideration would be among the least likely to be involved. If the basement shelters are designed for 50 p.s.i. they will have to be sealed against the entry of blast and should therefore provide complete protection from fire even if the building over and the surrounding buildings are engulfed in a conflagration. If they are designed for 10 p.s.i. and are therefore not sealed there would be some fire hazard to the occupants, but it would be small and they might have time to seek alternative accommodation if their building appeared likely to be engulfed.

11. Flooding. Basements in low-lying parts of London would be in danger of flooding from a ground burst bomb which breached the Thames. However the crater would take some time to fill and the occupants should have plenty of time to leave before the floods threatened them. Damage to the building over the shelter, with consequent breakage of water mains, might pose a slow flooding risk. However there were few records of this type of incident in the last war and it is considered that the risk is trivial in comparison with the risks of blast and fall-out.

Ventilation

12. The normal* L.C.C. requirements for the ventilation of basement and sub-basement garages are that natural ventilation should be sufficient to provide for three air changes per hour and in addition mechanical ventilation

*In exceptional cases, where natural ventilation cannot be provided, an additional mechanised plant, capable of providing three air changes per hour, must be provided and must be capable of running should a failure occur in the principal source of power supply.

independent of any ventilating plant for other parts of the building should be provided sufficient to give three air changes per hour. The openings (amounting to not less than 2½% of the area of the floor of the garage) required for natural ventilation are normally provided by the ramp entrances to the garage, which are closed by gates of the lattice type to permit a free flow of air.

13. If the garage were used as an unsealed 10 p.s.i. shelter (see para. 3) then it is considered that natural ventilation (where provided) will be adequate. Moreover the air speeds involved in this natural ventilation are so low that there is little risk of dangerous fall-out particles being carried into the shelter by the ventilating air. Where natural ventilation is not provided, the requirement for a second means of ventilation, independent of the main source of supply, should ensure adequate ventilation if the garage is used as a shelter.

14. It therefore appears that only if the garage is naturally ventilated but is intended for use as a sealed 50 p.s.i. shelter (see para. 4) will there be any requirement for additional ventilation equipment. It is estimated that stand-by generators to provide the necessary power for this and for a degree of lighting would cost about £5 per shelter space.

Standard of Shelter to be adopted

15. The alternatives appear to be either to use the buildings virtually as they are as 10 p.s.i. shelters or to strengthen the ground floor slabs to provide Grade A (50 p.s.i.) shelters.

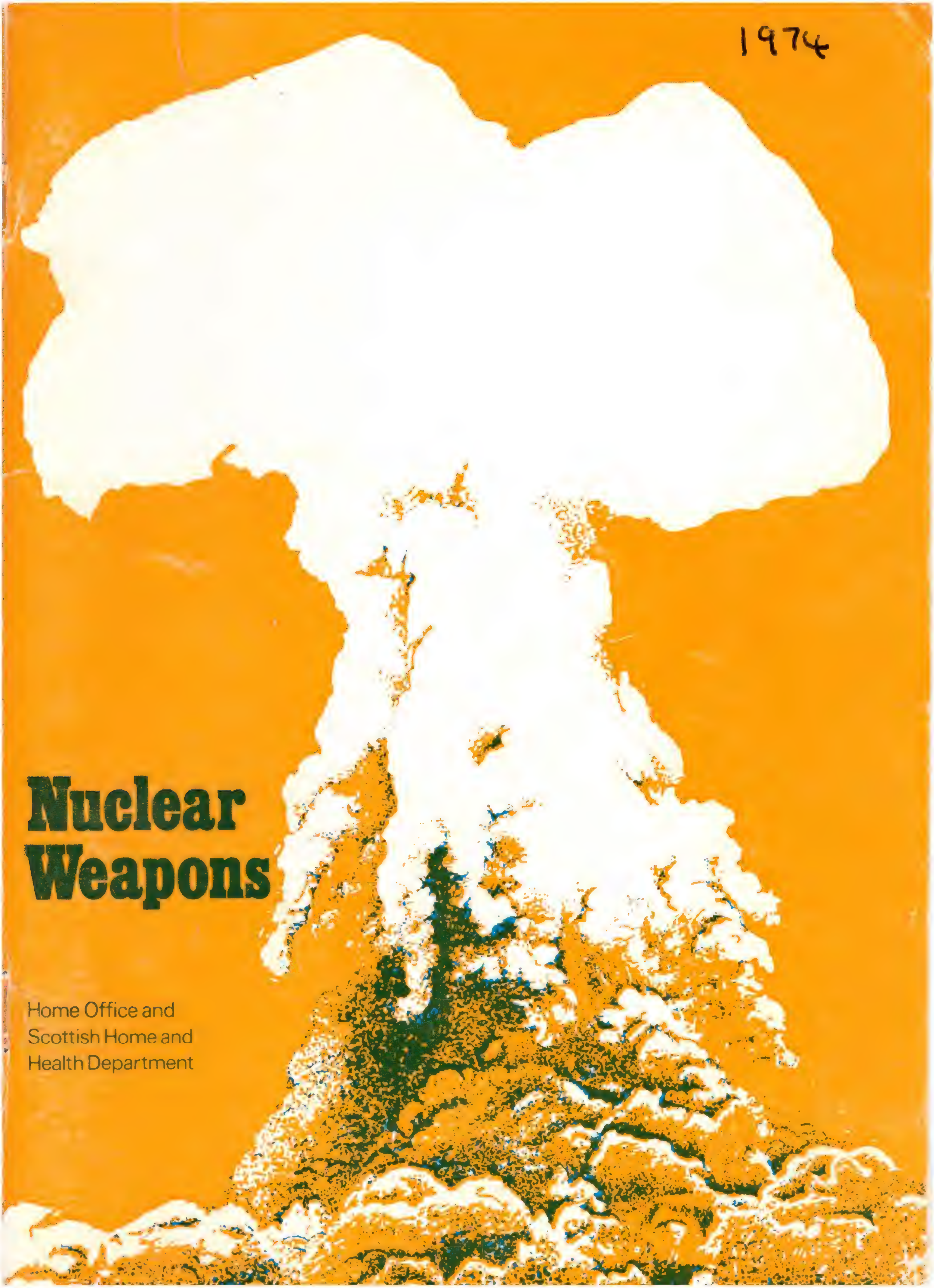
16. If the former course is adopted the only structural alteration worth consideration would be the thickening of unprotected parts of the ground floor slab to provide a protective factor of 200. The cost of this would be unlikely to exceed an average of £1 per shelter space (assuming that an average of 75% of basement garage space had a building over it and not just a ground floor slab). On the whole this is not considered to be

worthwhile expenditure. It would add nothing to the blast resistance of the shelter and the same effect as far as fall-out is concerned could be achieved, without cost, by excluding the use as shelter of inadequately protected parts of the basement.

17. The existing provisions for ventilation should be satisfactory for 10 p.s.i. shelters, and the only provisions which would have to be made in peacetime would therefore be the provision of standby generating plant for lighting purposes and the provision of water storeage for the shelter occupants. These are comparatively trivial provisions which could do little to promote public confidence in the buildings as shelters and there would seem to be little justification for making them at the present time. If nothing is done we shall still be accumulating potentially useful shelter space at the rate of about 200,000 shelter spaces per year in the L.C.C. area alone, and the provision of standby generating capacity and water storage could well be left till war seems more imminent.

18. The strengthening of the ground floor slabs to 50 p.s.i. (Grade A) would cost about £20 per shelter space and, since the shelters would be sealed, provision would also have to be made for standby generating equipment to work the ventilation system in event of power failure. The cost of this and the other measures required (e.g. water storage) should not exceed £5 per shelter space, so that the total cost of providing really first class shelter would be about £25 per head. If this were applied to all the new buildings in the L.C.C. area alone it would entail an annual cost of about £6 million.

1974



Nuclear Weapons

Home Office and
Scottish Home and
Health Department

5.16 In the last war fire storms were caused in the old city of Hamburg as a result of heavy incendiary attacks and at Hiroshima but not Nagasaki. A close study of these fire storms and of German cities in which fire storms did not occur revealed several interesting features. A fire storm occurred only in an area of several square miles, heavily built-up with buildings containing plenty of combustible material and where at least every other building in the area had been set alight by incendiary attack.

5.17 It is considered unlikely that an initial density of fires, equivalent to one in every other building, would be started by a nuclear explosion over a British city; studies have shown that due to shielding a much smaller proportion of buildings than this would be exposed to heat flash. Moreover, the buildings in the centres of most British cities are now of fire-resistant construction and more widely spaced than 30–40 years ago. Fire storms after nuclear attack are therefore unlikely in British cities but the possibility would be greatly reduced by the control of small initial and secondary fires.

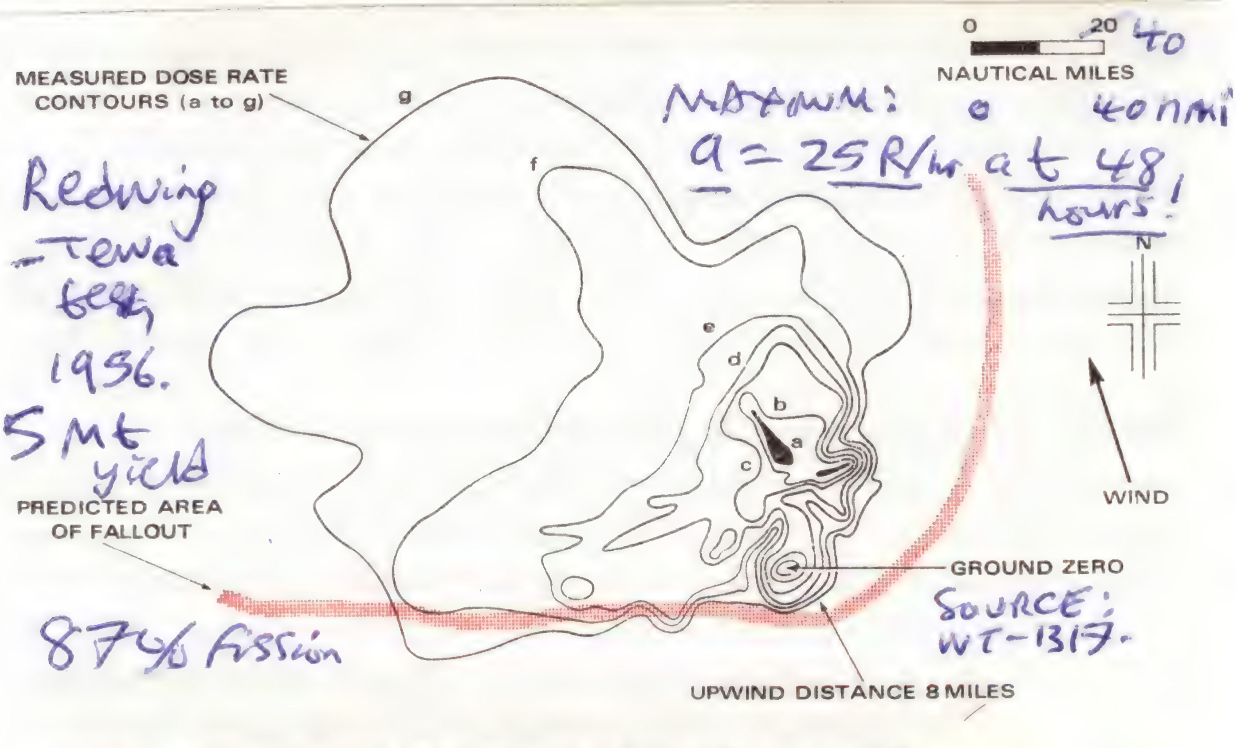


Figure 4 Comparison of fallout prediction with test results

Table 23 Approximate protective factors in ground floor refuge rooms of typical British housing with timber upper floors and with windows and external doors blocked

Types of housing	Protective factor
Bungalow	5–10
Detached two-storey	15
Semi-detached two-storey 11 inch cavity walls	25–30
Semi-detached two-storey $13\frac{1}{2}$ inch brick walls	40
Terraced two-storey	45
Terraced back-to-back	60
Blocks of flats and offices (see paragraph 9.1) Lower floors	50–500
second floor and above (decreasing)	50–20

(ASSUMES 100% FALLOUT RETENTION ON ROOF + HIGH ENERGY ~1 MeV γ-FALLOUT)

9.20 The amount of fallout retained in the United Kingdom on a clean dry roof with a slope of about 30° (about 1 in 2) or more would be insignificant. If the roof were damp, most of the fallout would be retained until it becomes dry. Rainfall, other than a very light drizzle, would wash fallout off the roof. Consequently the protective factors of prepared refuges in most British houses may be higher than the values given in Table 23. Except in prolonged damp weather, the additional protection could be significant in houses with clean steep roofs having a low protective factor where a large part of the radiation is assumed to come from the roof. ← BASED ON DETAILED HO, SAB, EXPERIMENTS!

Basements and trenches

9.21 A substantial increase in protection is obtained in cellars or basements, or in trenches under the floor. For example a trench under a detached two-storied house could give a PF of about 100 and a basement of between 50 and 100, if all the floor was 5 feet below ground level.

9.22 A properly constructed slit trench in the open with 3 feet of earth cover would have a protective factor of 200 or more.

10·6

fallout could be washed into street drains. Most of it would be trapped there until it decayed and it would not constitute a significant hazard because of the depth underground. Arrangements might be necessary to dispose of heavily contaminated drainage with the least harm to water supplies and sewage disposal.

10·16

Cereals—Wheat, barley etc. Fallout particles lodge mainly in the outer part of the ear. The threshing process and rejection of the husk fraction after milling would remove up to 90 per cent of the original contamination.

Root crops—Potatoes, beet etc. The direct contamination hazard to the root is negligible. Rejection of the contaminated tops, washing and/or peeling of the root would give almost complete decontamination.

Surface crops, open leaf—Cabbage, lettuce etc. The rough leaf and open structure of this class of vegetables could result in high retention of fallout particles. These vegetables, which have a low energy value, could be used after rejecting the outer leaves and washing the remainder.

Surface crops, legumes—Peas, beans etc. The pod structure of this class of vegetables provides a natural protective cover, and pod removal ensures almost complete decontamination.

Hard fruits—Apples, pears etc. The acts of washing and peeling provide almost 100 per cent decontamination.

Eggs, milk and fish

10.19 Eggs, derived from exposed but surviving animals, would not contain enough radioactivity to present a serious ingestion hazard. Most fission products are eliminated via the egg shells. Free-range hens would obviously be at greater risk of dying than those kept under cover. Thyroid damage from the consumption of eggs from apparently healthy poultry can be discounted.

10.20 The main ingestion hazard in the immediate post-attack period is presented by the consumption of milk and milk products, obtained from dairy cattle which have grazed contaminated pastures. Owing to the concentration of radioactive iodine in the animal thyroid and its rapid transfer into the milk, the radioiodine level would reach a maximum after about two to three days. The risk to children would be avoided by the use for, say, three weeks of milk powder, milk substitutes or milk from cows kept under cover and fed on uncontaminated fodder. Contaminated milk could be used to prepare products such as cheese or butter, where normal storage prior to consumption would allow the decay of the short-life iodine isotopes (see paragraph 10.2). (I-131 = 8 days half-life

10.21 Radiation effects on freshly caught fish in the immediate post-attack period can be discounted. Shellfish and crustaceans from coastal areas of heavy fallout would constitute a risk but this source of food is relatively small.

Appendix I Atoms and the Structure of Matter: Some Definitions

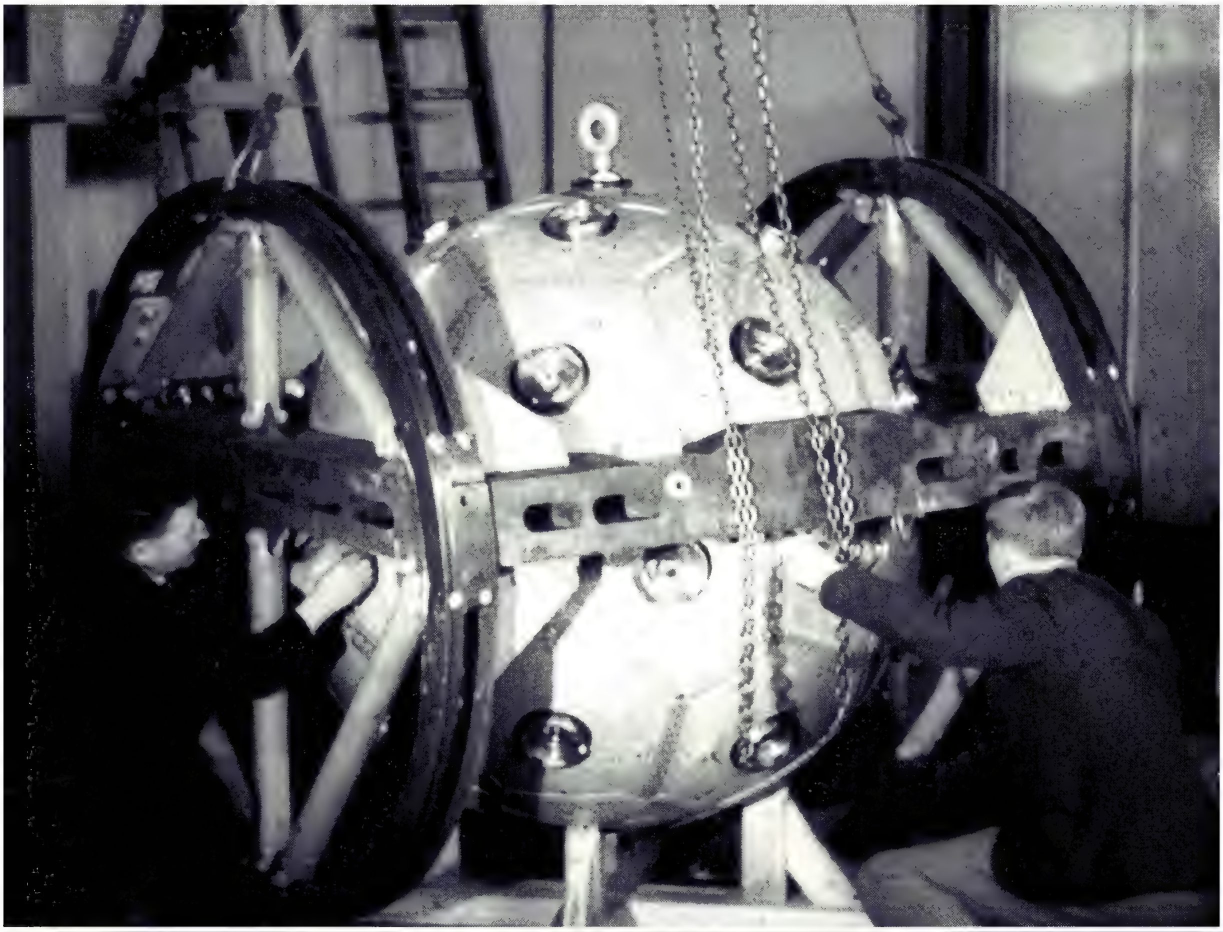
1. A little knowledge of the structure of matter helps towards an understanding of the effects of nuclear weapons. Matter consists of an assembly of atoms of various ELEMENTS interspersed in space at relatively great distances from one another. The metals iron and aluminium, the non-metal sulphur and the gases hydrogen, oxygen and nitrogen are among the more common of the 105 different elements now known and some of these elements like plutonium are man-made. Each element has characteristic chemical properties by which it can be distinguished from all the other elements.

2. An ATOM of an element is the smallest particle which can exhibit the chemical properties of that element. For example, if single atoms of iron were broken up, the pieces would have the recognisable properties of quite different elements. Atoms are exceedingly small, far smaller than the limit of visibility under a microscope: nevertheless, most of the matter contained in each atom is concentrated in a central nucleus which is about 10,000 times smaller. A nucleus always carries one or more positive electrical charges and, in the normal state, it is surrounded by a cloud consisting of an equal number of negatively charged particles called ELECTRONS, so that the atom as a whole is electrically neutral. These electrons can be imagined as moving in orbits around the nucleus like planets around the sun.

3. A nucleus contains two main types of fundamental particle each of which is about 1,840 times as massive as the electron:

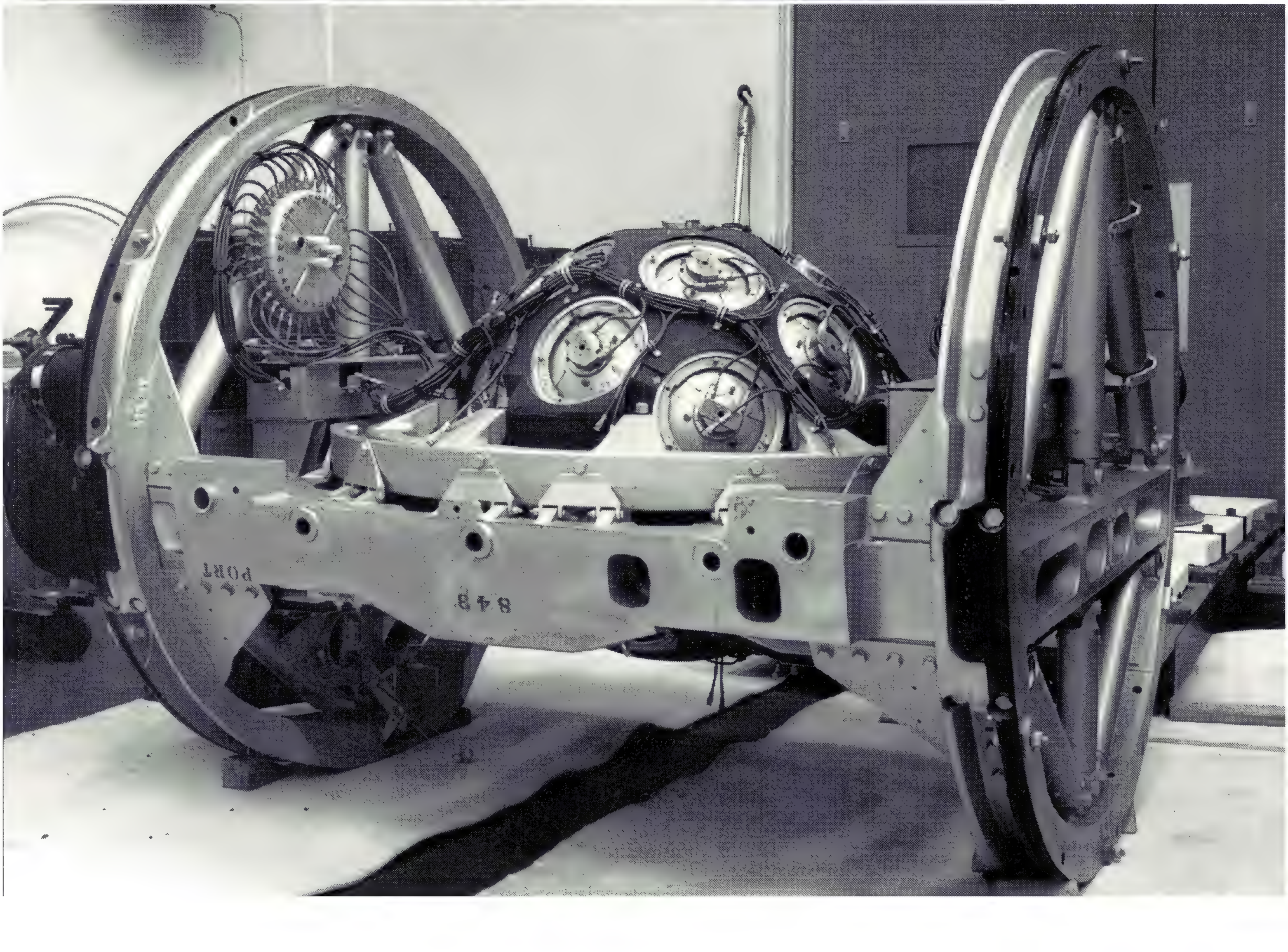
A NEUTRON with no electrical charge,
A PROTON with a positive charge.

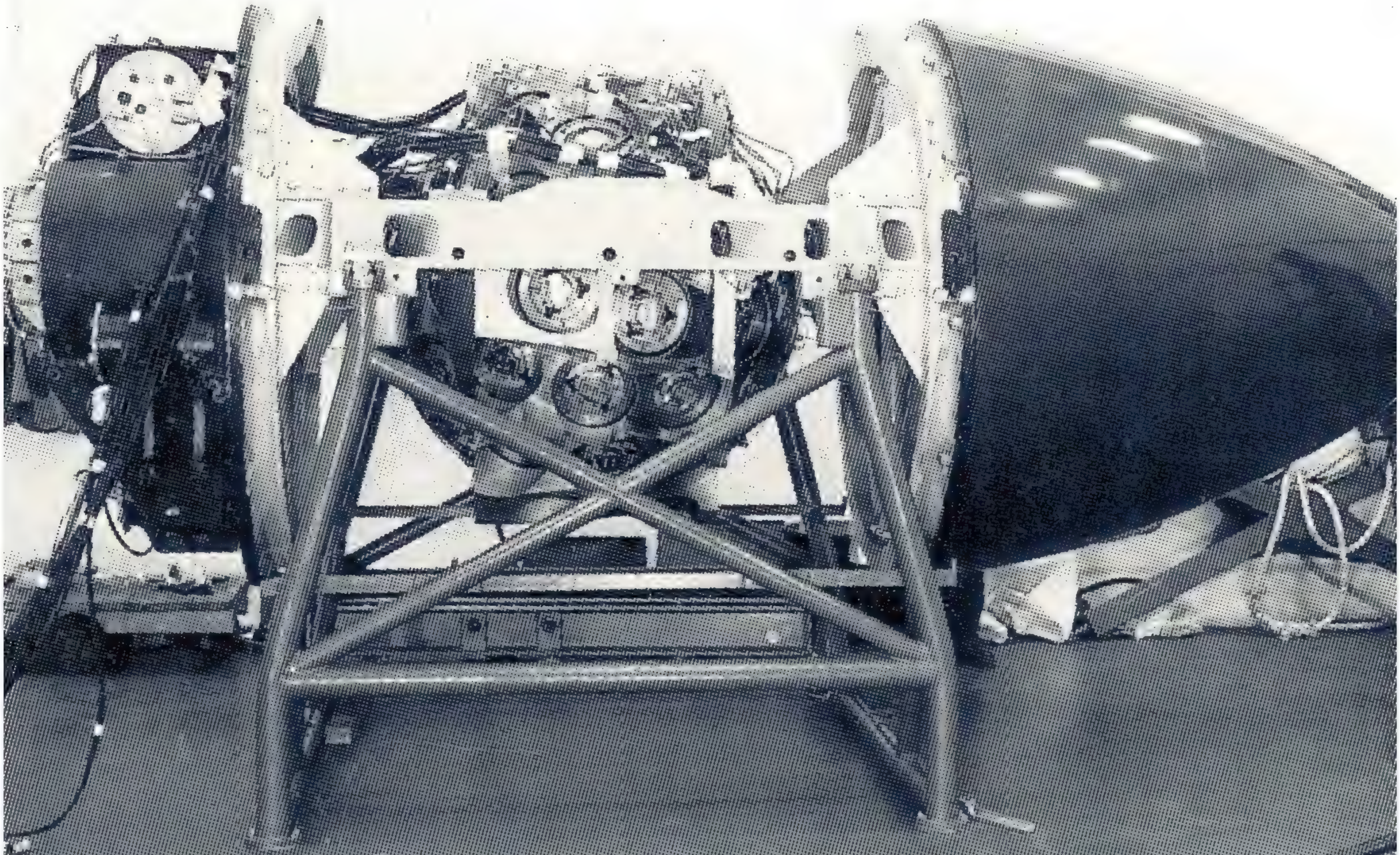
Because of the repulsive forces between positive charges, nuclei cannot approach one another very closely, but an uncharged neutron can approach and hit another nucleus without being repelled. The energy released in an atomic reactor or in the detonation of a nuclear weapon is part of the large quantity of binding energy which holds the particles together in the nucleus.



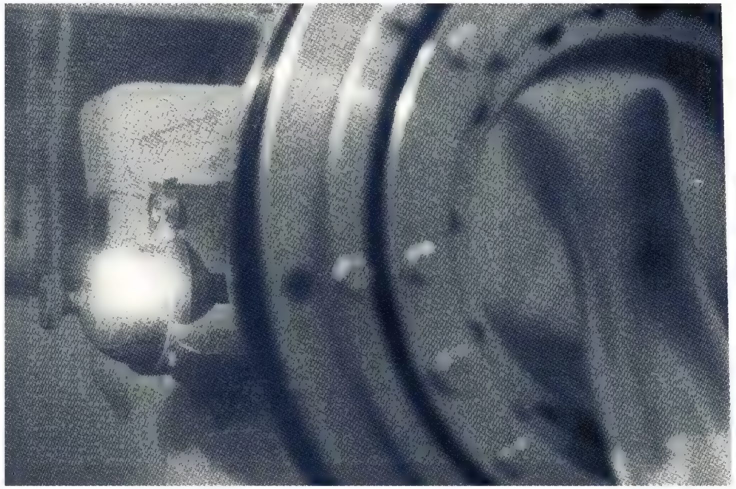
Comparison of 25 kt UK 1952 bomb Hurricane (6.19 kg Pu239 core), top, and 720 kt pure fission U235 implosion bomb Orange Herald, below. **117kg hollow U235**

(5 ft diameter "wheel" cradles support nuclear weapons inside bomb drop case)

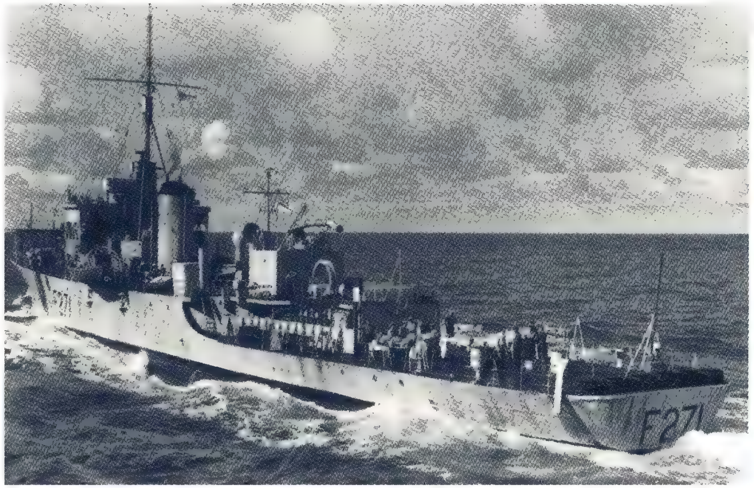




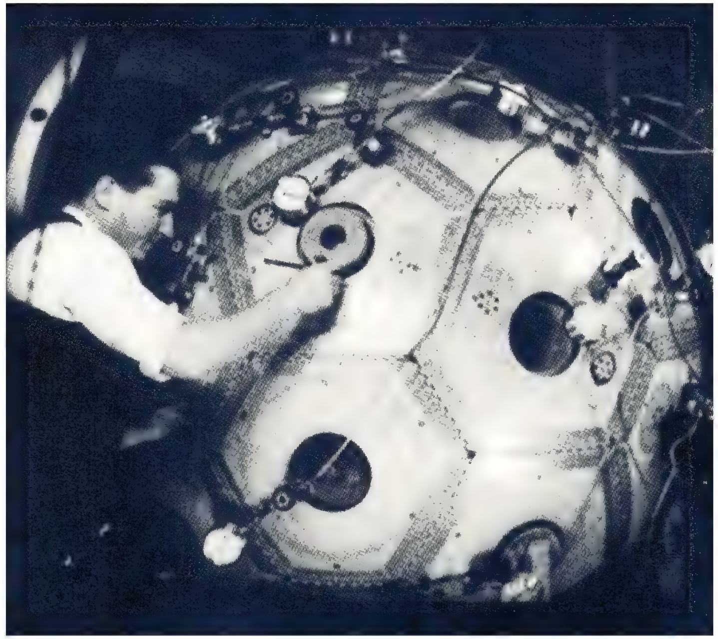
UK "GREEN GRASS" IMPLOSION DEVICE INSIDE BLUE DANUBE



First plutonium hemisphere for 3 October 1952 Hurricane nuclear test, cooling inside a radiation proof glove box (glove port in thick glass window for hand insertion is visible at right), building A1.1, taken on 23 July 1952. Both hemispheres were flown out to Monte Bello by Sunderland flying boat.

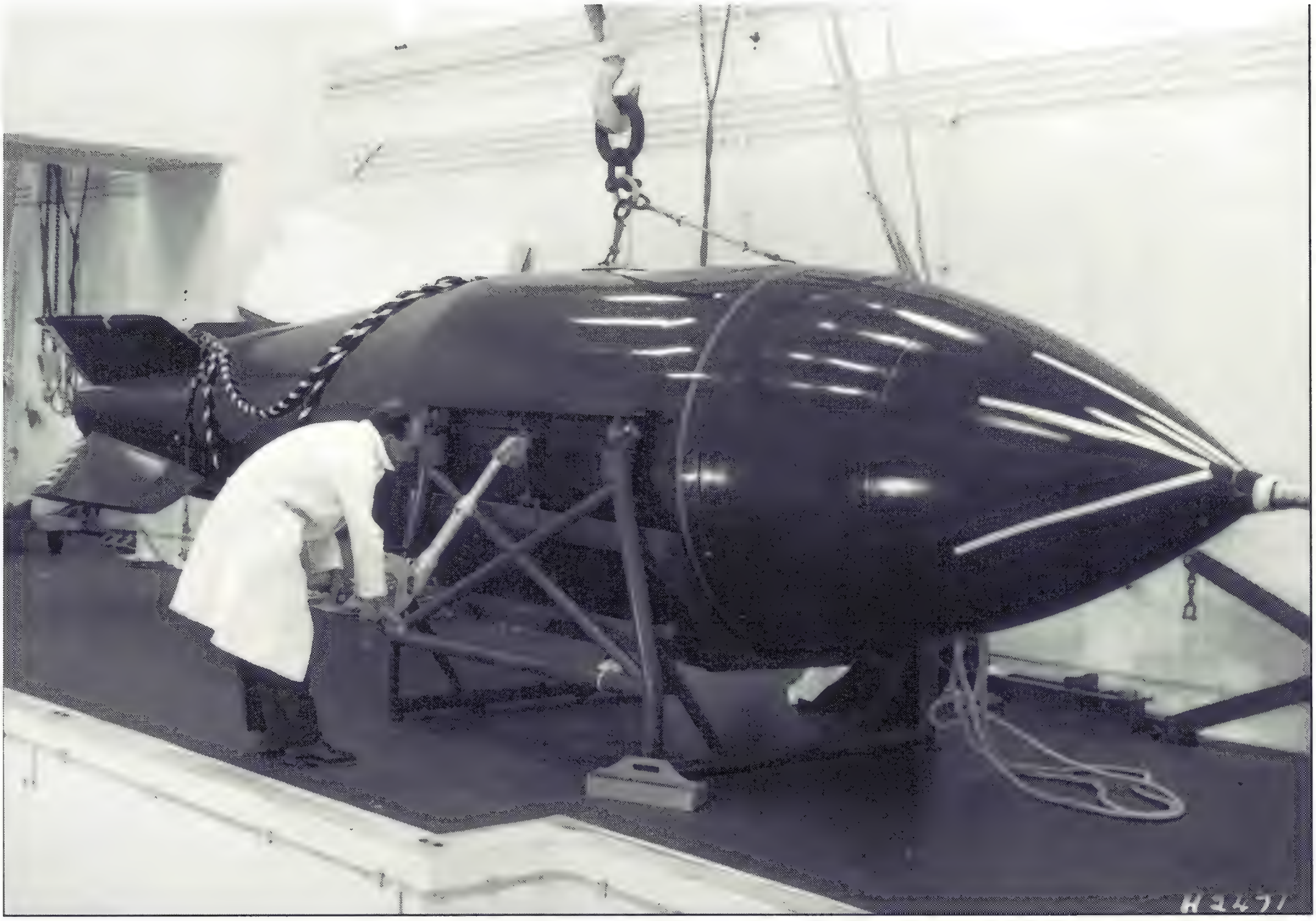


HMS Plym, a wartime convoy frigate of 1,450 tons, was loaded with a nuclear weapon and blown up with 25 kt yield on 3 October 1952 at Monte Bello, Australia, to simulate the effects of a clandestine Russian surprise attack on a harbour or military port in the model of the 1941 Pearl Harbor knockout blow.

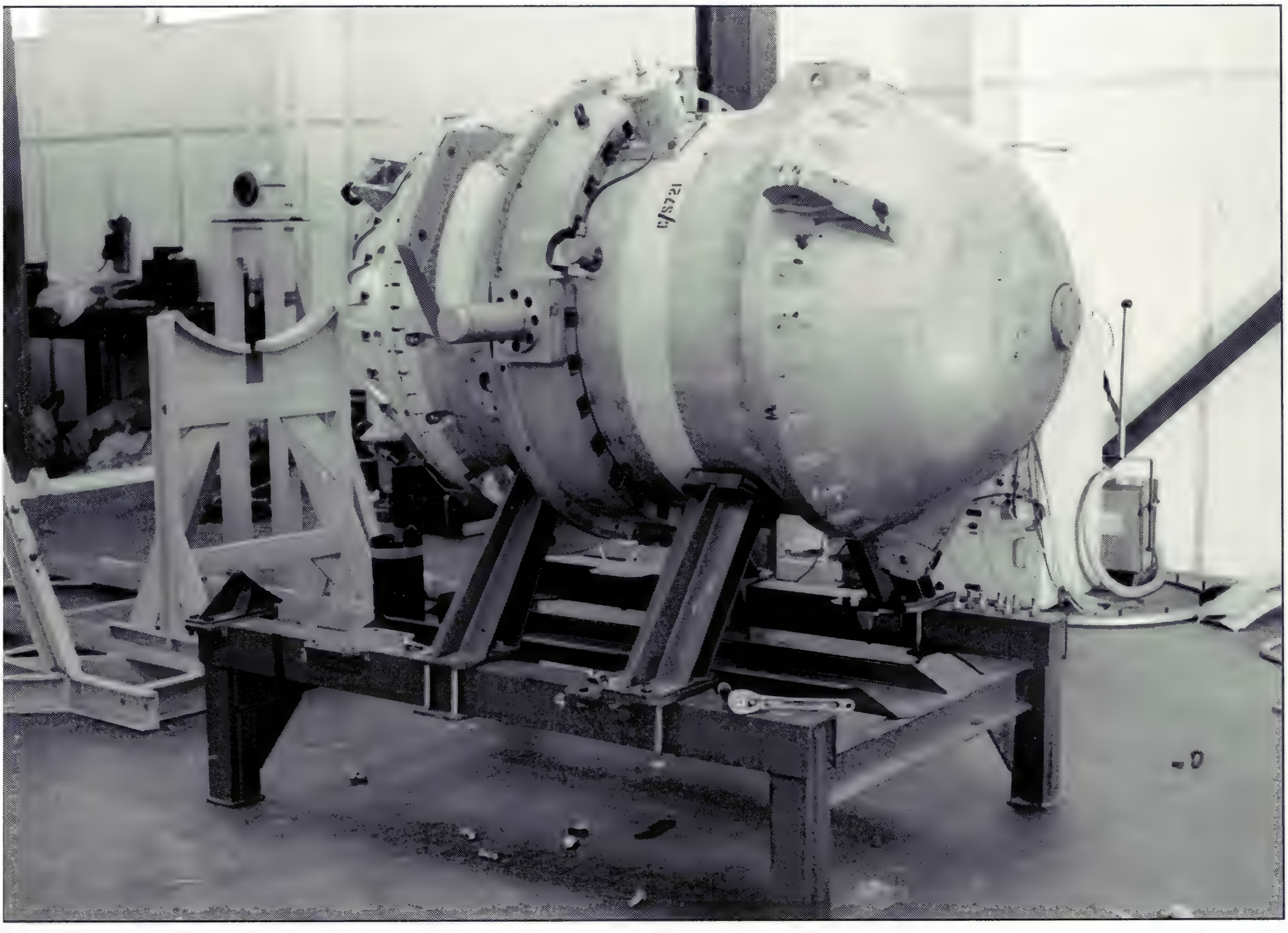


The first British nuclear weapon design (above, being assembled at RAF Farnborough in 1952)
Simple implosion, with pentagons and hexagons for lenses (huge detonators)

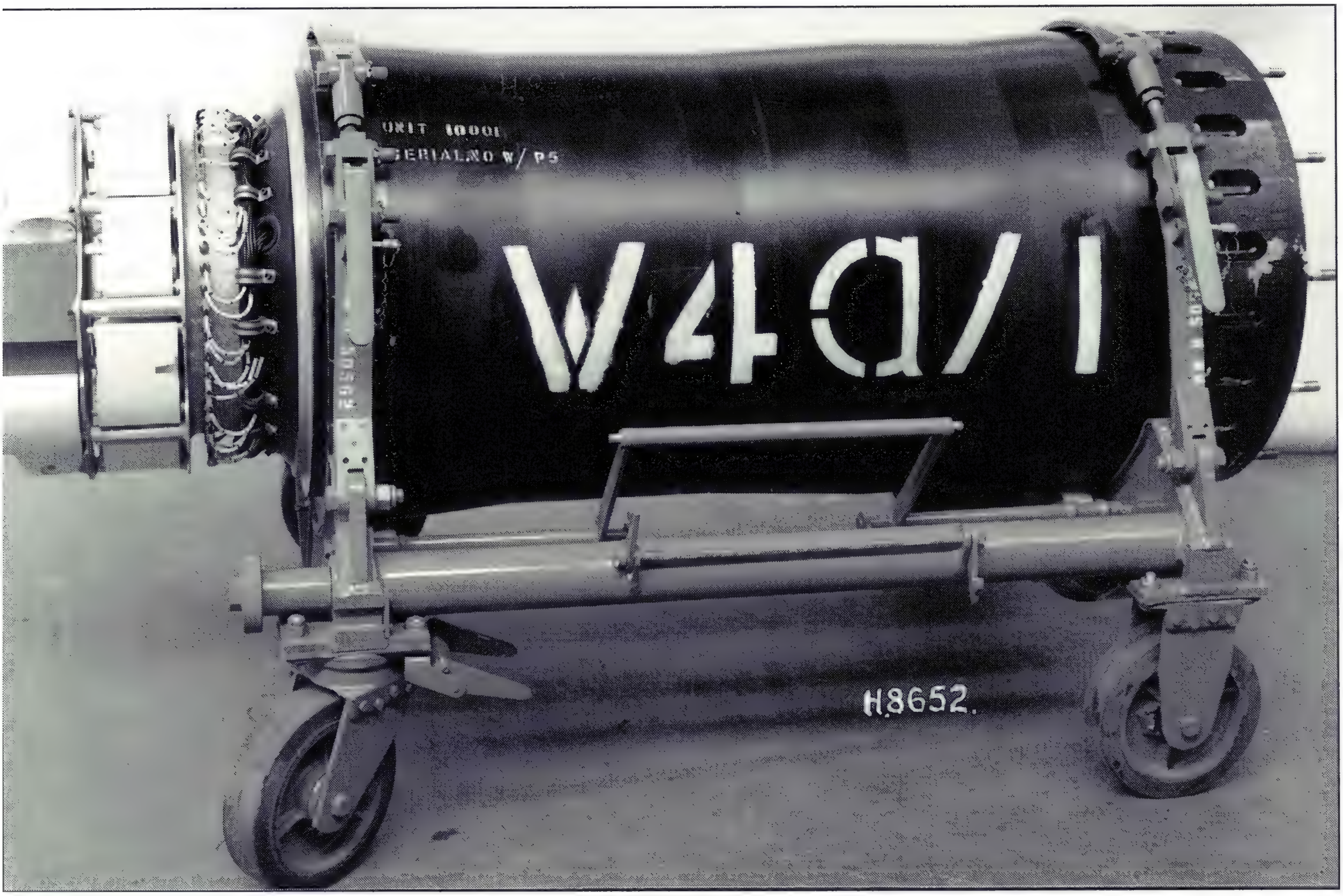
UK's last tactical nuclear WE177 destroyed: 31 March '98



24 ft long, 5 ft diameter Blue Danube UK 1957 H-bombs air burst drop casing



300 kiloton, spherical secondary stage, two-stage thermonuclear Short Granite



UK 1.1 megaton Red Snow (copy of American B28 cylindrical secondary bomb)

UK Grapple Z - Halliard 3-stage bomb (primary, fission secondary, and thermonuclear tertiary stages; all spheres), tested 11 September 1958 at American request (data exchanged for American B28 thermonuclear weapon).


Upshot-Knothole Climax

HANDBOOK OF NUCLEAR WEAPON EFFECTS

Calculational Tools Abstracted From DSWA's Effects Manual One (EM-1)

John Northrop

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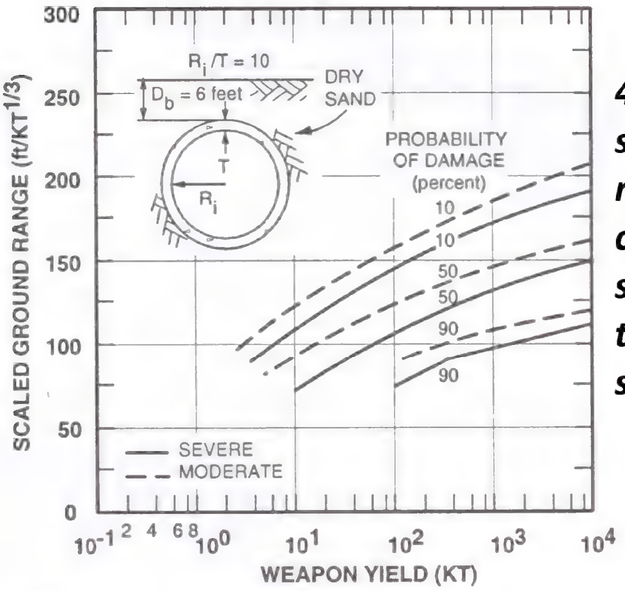


4500psi stress reinforced concrete silos and tube shelters

Figure 15.52. Vulnerability Curves for a Horizontal Cylinder, Aspect Ratio $R_i/T = 10$ (Structure Category 15.3.18) Buried in Dry Sand.

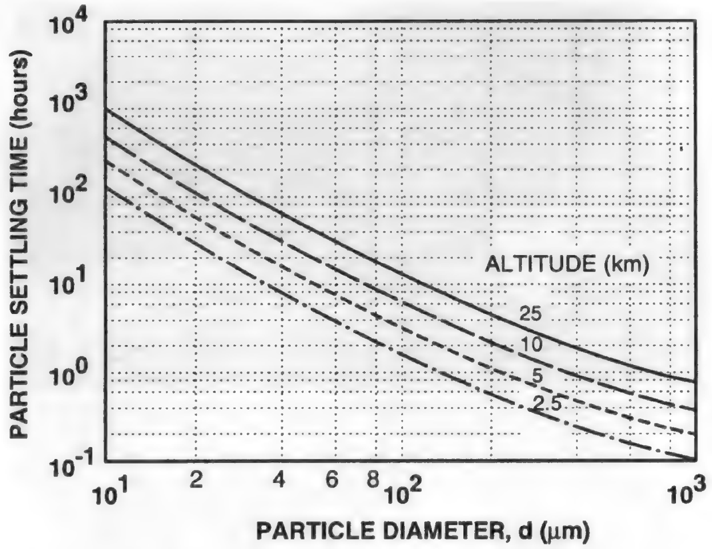


Figure 4.3b. Particle Settling Time(s) in Still Air Versus Small Particle Diameter (micron).

Figure 15.62. Basic Vulnerability Chart for Tunnels in Rock.

LIMITS OF SURVIVABILITY IN GRANITE FOR 1 MT

TYPE OF LINING	SLANT RANGE, R (feet)
SPECIAL COMPOSITE	600 – 700

Table 14.1. Combat Ineffectiveness for Personnel in an Open Two-Man Foxhole (2 x 6 x 4.5 feet) Side-On to Blast Wave.

COMBAT INEFFECTIVENESS (%)	WEAPON YIELD (KT)					
	0.01	0.1	1	10	100	1,000
	PEAK INCIDENT OVERPRESSURE (psi)					
99	52	38	38	38	38	38
50	37	29	29	29	29	29
1	25	21	21	21	21	21

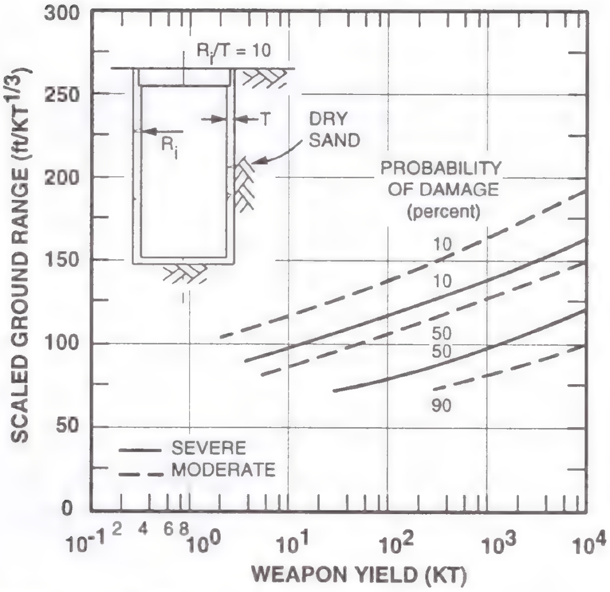


Figure 15.60. Vulnerability Curves for a Vertical Cylinder, Aspect Ratio $R_i/T = 10$ (Structure Category 15.3.24) Surface Flush in Dry Sand.

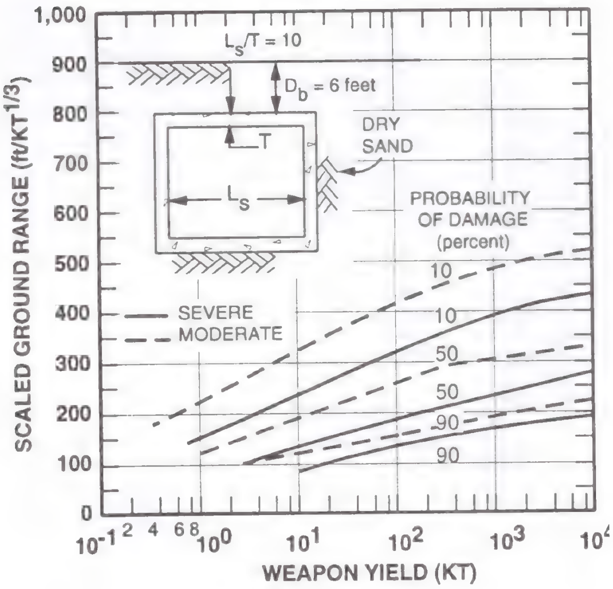


Figure 15.35. Vulnerability Curves for a Flat-Roofed Structure, Aspect Ratio $L_s/T = 10$ (Structure Category 15.3.3) Buried in Dry Sand.

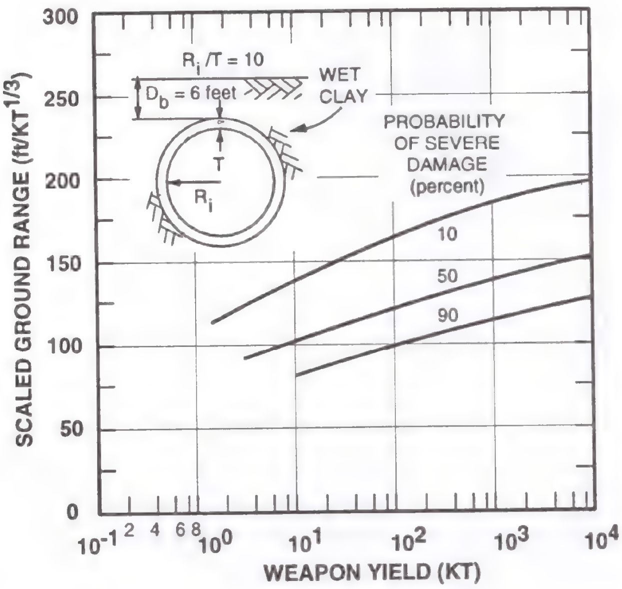


Figure 15.55. Vulnerability Curves for a Horizontal Cylinder, Aspect Ratio $R_i/T = 10$ (Structure Category 15.3.21) Buried in Wet Clay.

Table 15.15. Field Fortification Damage Criteria.

STRUCTURE CATEGORY	STRUCTURE TYPE	STRUCTURE DESCRIPTION	DAMAGE DESCRIPTION		
			SEVERE	MODERATE	LIGHT
15.7.1	MGEs	Machine-gun emplacement, 7 x 7-foot framework extending 2 feet above original ground surface, has open firing ports and open trench entrance; 3- to 5-foot mound of earth cover extends down to the surface except at openings.	Caps and posts broken, large displacement and disarrangement of timbers, revetment failure.	Some caps and posts broken, moderate displacement, some revetment failure.	Damage to minor components only, slight displacement, occasional revetment failure.
15.7.2	CPs	Command post and personnel shelter, modular sections 6 x 8 feet with top 3 to 5 feet below the ground surface; earth covered, and covered trench entrance.	Caps and posts broken, large displacement and disarrangement of timbers, revetment failure.	Some caps and posts broken, moderate displacement, some revetment failure.	Damage to minor components only, slight displacement, occasional revetment failure.
15.7.3	Shelters	A hardened frame/fabric shelter with sealed vertical entryway, buried with at least 4 feet of cover.	Complete collapse of shelter frame and total filling of shelter by overburden.	Large deflections of frame and entryway, partial filling of shelter.	Minor displacement of shelter and entryway.
15.7.4	Trenches	Unrevetted trenches and foxholes with or without light cover.	At least 50 percent filled with earth.	At least 20 percent but less than 50 percent filled with earth.	Less than 20 percent filled with earth.

Table 15.16. Machine Gun Emplacement Vulnerability Levels.

PERCENT PROBABILITY OF DAMAGE	LEVEL OF DAMAGE		
	LIGHT	MODERATE	SEVERE
	Peak overpressure (psi)		
10	15	35	45
50	25	50	65
90	35	75	100
	Peak dynamic pressure (psi)		
10	1.3	10	20
50	2	15	30
90	3	23	45

Table 15.17. Command Post and Personnel Shelter Vulnerability Levels for Peak Overpressure (psi).

PERCENT PROBABILITY OF DAMAGE	LEVEL OF DAMAGE		
	LIGHT	MODERATE	SEVERE
10	20	35	40
50	30	50	60
90	45	75	90

Table 15.18. Hardened Frame/Fabric Shelter Vulnerability Levels for Peak Overpressure (psi).

PERCENT PROBABILITY OF DAMAGE	LEVEL OF DAMAGE		
	LIGHT	MODERATE	SEVERE
10	20	35	40
50	30	50	60
90	45	75	90

FIG. 2.3: 1 kt free air burst (sea level air density) peak overpressure

$P = 3.04 \times 10^{11} / R^3 + 1.13 \times 10^9 / R^2 + 5 \times 10^6 /^R$ Pascals +/-15%, R in metres

for surface bursts, set $R = 2^{-1/3}$

FIG. 2.6: 1 kt free air burst (sea level air density) total overpressure impulse

$I_p = 10^6/R$ Pa-sec +/-20%, R in metres.

FIG. 2.7: 1 kt free air burst (sea leve air density) total dynamic pressure impulse

$I_q = 10^9 / R^{2.5}$ Pa-sec +/-20%, R in meters (valid: R > 150m).

8. NUCLEAR RADIATION PHENOMENA

8.1 Introduction. Although the radiation from nuclear explosions includes gamma rays, neutrons, beta particles, and alpha particles, only the first two elements are transported over significant distances through matter, and thus are the only ones considered in detail in this chapter. The exceptions to this are high-altitude explosions in which beta-particle phenomena occur over large distances, and direct contact with fallout in which beta particles, and to a lesser extent and only at very late times, alpha particles, may be significant.

8.2.2 Weapon Radiation Sources.

8.2.2.1 Generic Weapon Types. *EM-1* contains a complete description of 13 generic weapon types and extensive data on the atmospheric transport of their several types of radiation outputs. Table 8.4 is an abstract of four of these types. In general, the data in this handbook are the subset of the *EM-1* data for these types.

Table 8.4. Representative Types of Nuclear Weapons.

TYPE	DESCRIPTION
3	Unboosted fission implosion weapon, contemporary design
5	Boosted fission implosion weapon, modern design
8	Thermonuclear secondary
13	Enhanced radiation thermonuclear secondary

8.2.2.3 Gamma-Ray Sources. For most weapon designs (Table 8.6), the range of gamma-ray production efficiency as a percent of total yield ranges from 0.1 to 0.5 percent, with the larger gamma yields attributed to those weapons that are physically the smallest. Average gamma-ray energy depends more on the origin of the weapon yield (fission or fusion) and the physical size of the weapon than on the yield itself. Small weapons and those that obtain a large fraction of their yield from the fusion process tend to have the highest average gamma ray energies.

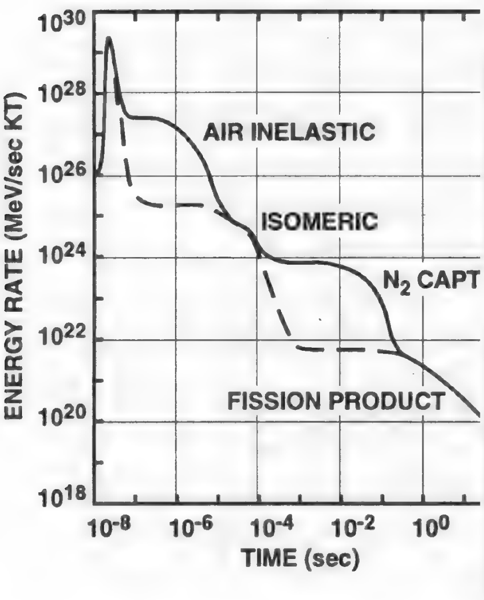


Figure 8.1. Idealized Time Dependence of the Gamma-Ray Output from a Large Yield Explosion, Normalized to 1 KT.

Table 8.5. Neutron Source Spectra and Output for Types 3, 5, 8, and 13.

ENERGY RANGE (MeV)		NEUTRONS PER MeV			
UPPER	LOWER	SOURCE 3	SOURCE 5	SOURCE 8	SOURCE 13
1.49×10^{1}	– 1.22×10^{1}	8.85×10^{-5}	9.47×10^{-3}	1.65×10^{-2}	1.42×10^{-1}
	NEUTRONS PER KT	2.70×10^{23}	3.38×10^{23}	1.95×10^{23}	1.77×10^{24}

Table 8.6. Weapon Gamma-Ray Output.

WEAPON TYPE	TOTAL GAMMA-RAY ENERGY [a] (MeV/KT)	AVERAGE GAMMA-RAY ENERGY (MeV)	PEAK GAMMA-RAY OUTPUT RATE [a, b] (MeV/nsec-KT)
3	9.80×10^{22}	1.50	4.92×10^{21}
5	1.04×10^{23}	1.61	5.22×10^{21}
8	$3.55 \times 10^{23} \times W^{-0.29}$	1.63	$1.79 \times 10^{22} \times W^{-0.29}$
13	6.70×10^{23}	2.00	3.37×10^{22}

Notes: a - W is yield in kilotons.
b - Illustrative values based on a hypothetical prompt gamma-ray pulse duration of 20 nsec

Table 8.10. Height of Burst and Yield Range for Generic Device Types.

Device Type	Data HOB (meters)	HOB Range (meters)	Yield Range (KT)
Enhanced Radiation (ER) (13)			
Low Yield	75	50 - 100	1 - 5
High Yield	200	100 - 300	5 - 15
Thermonuclear (8)	200	150 - 500	10 - 500
Boosted Fission (5)	160	60 - 300	1 - 20
Fission (3)	150	60 - 300	0.5 - 15

Table 8.12. Critical Target Composition of Soil Types.

Soil Type	*Percent by Weight*				
	Sodium	Silicon	Aluminum	Maganese	Iron
Mojave	3.30	23.5	9.57	0.14	7.31
European	1.39	28.3	4.05	0.12	1.98
Nevada Area 7	0.80	25.3	7.70	0.07	1.52
Dade County	0.12	45.4	0.03	0.01	0.06

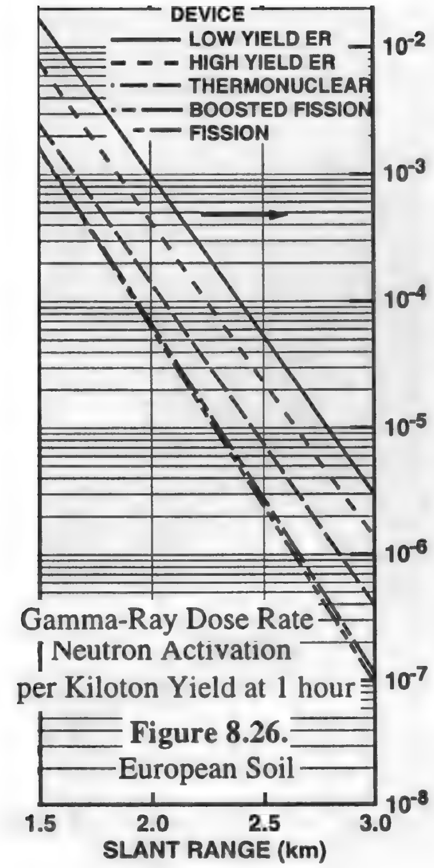


Figure 8.26. Gamma-Ray Dose Rate Neutron Activation per Kiloton Yield at 1 hour European Soil

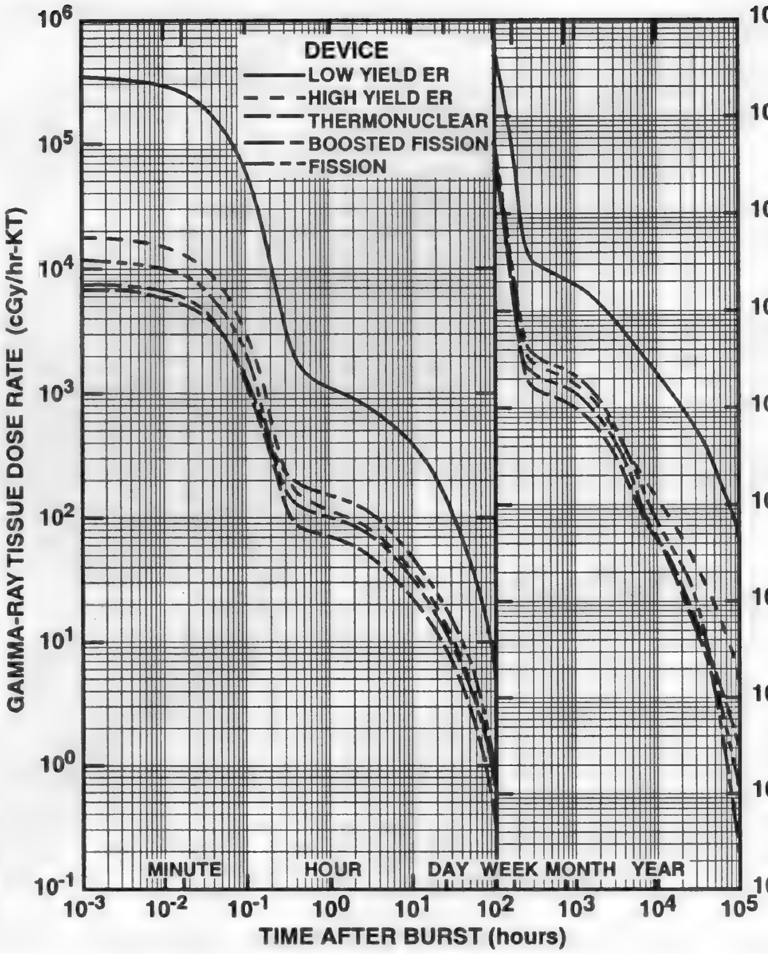


Figure 8.28. Gamma-Ray Dose Rate per Kiloton Yield at Ground Zero Neutron Activation of European Soil for Various Nuclear Weapon Types.

Figure 8.45. Fraction in Main Cloud.

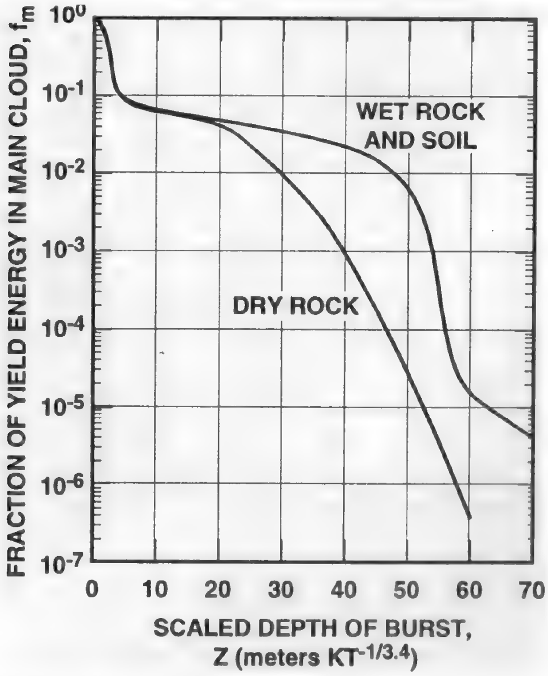
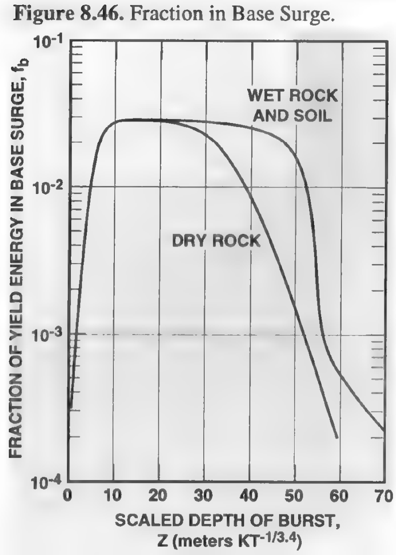


Figure 8.46. Fraction in Base Surge.



4.2.3 Dust Mass Loading.

Surface Bursts (SHOB < 5 ft/KT$^{1/3}$). The collected and analyzed soil and saltwater particles provide estimates of the lofted mass in nuclear clouds. The empirical relation from combining the soil and saltwater data for scaled mass in stabilized surface burst clouds is:

$$M_{SB}/W = 0.62\ W^{-0.11}, \qquad (4.8a)$$

where W is the yield in KT and M_{SB} is in KT = 10^9 grams, or

$$M_{SB}/W = 0.29\ W^{-0.11}, \qquad (4.8b)$$

where W is in MT and M_{SB} is in Mt = 10^{12} g.

Airbursts (SHOB ≥ 5 ft/KT$^{1/3}$). The experimental mass loading data have large scatter. DICE/TASS calculations have been used with these experimental data to generate the following approximated main cloud mass loading relationship with SHOB.

$$M/W(KT/KT) = 0.25\ \exp(-SHOB/75) + 0.04(1-SHOB/800) \qquad (4.9a)$$

for $5 \le SHOB \le 800$ ft/KT$^{1/3}$, and

$$M/W = 0 \text{ for } SHOB > 800 \text{ ft/KT}^{1/3}. \qquad (4.9b)$$

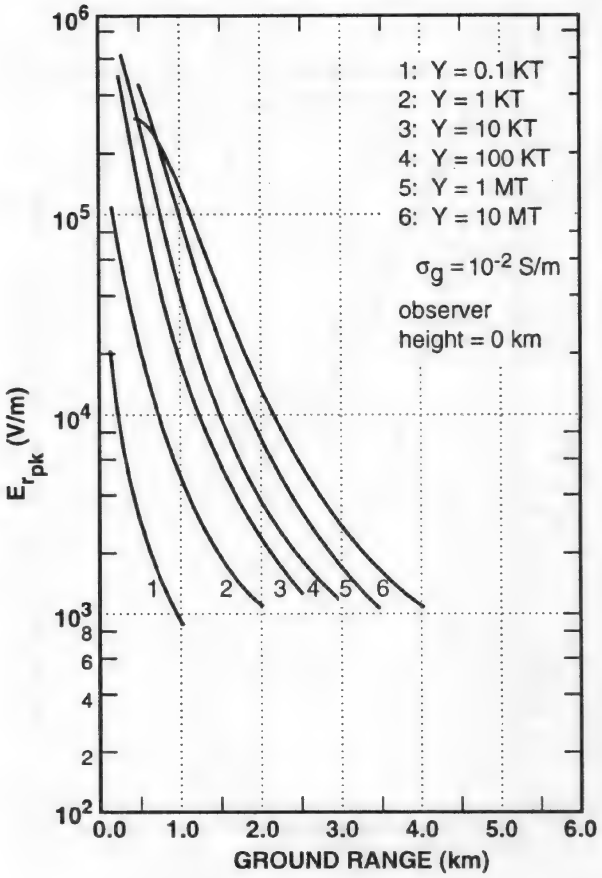


Figure 10.14. Variation of Peak Radial Electric Fields with Range from a Surface Burst for Various Total Yields.

EMP EFFECTS

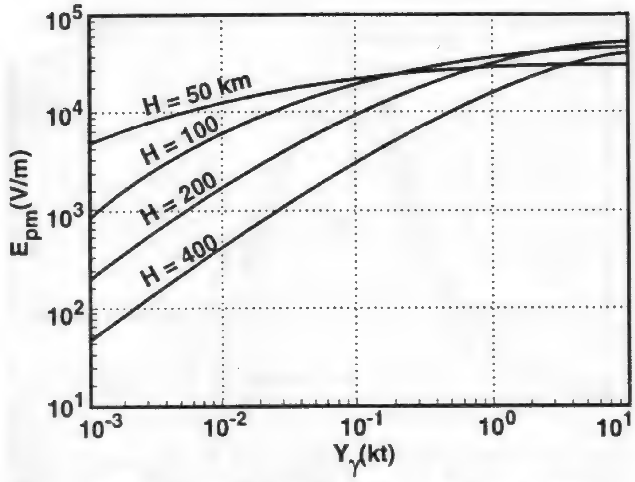


Figure 10.4. Maximum Estimated Peak Electric Field Versus Gamma Yield for Various Heights of Burst.

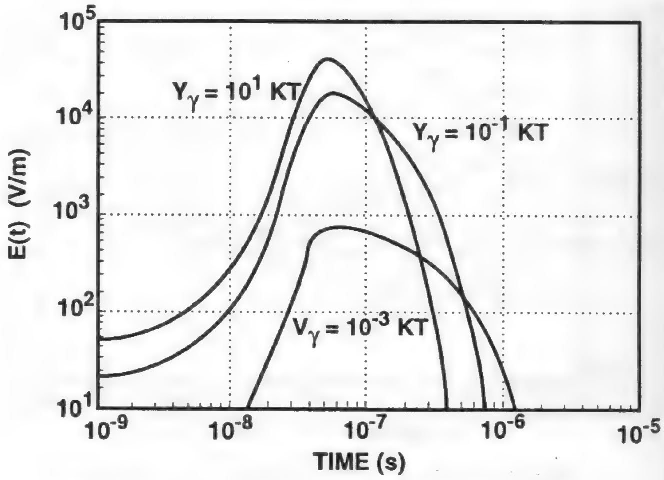


Figure 10.7. Electric Field Versus Time for Various Gamma Yields at 100 km.

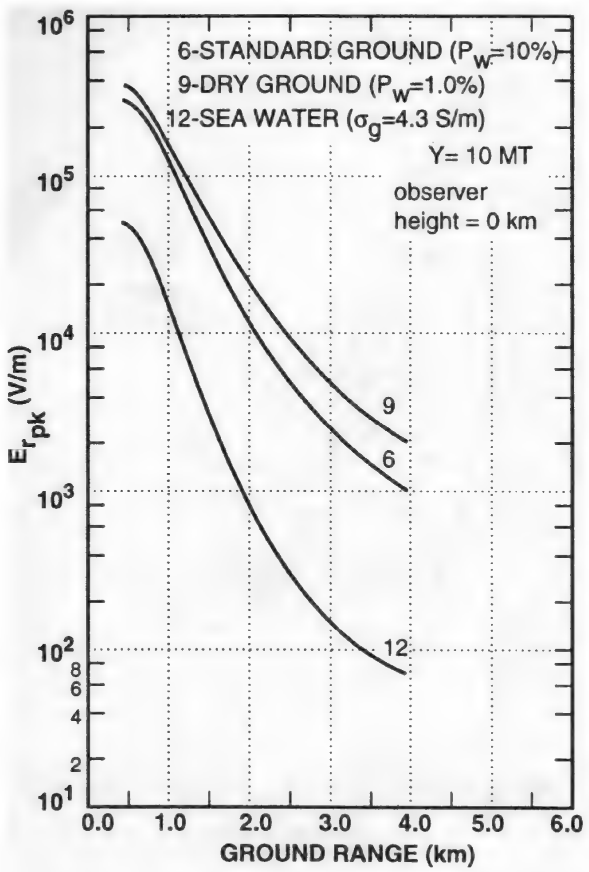


Figure 10.17. Variation of Peak Radial Electric Fields with Range from a Surface Burst for Different Ground Characteristics.

Figure 10.20. Generic Radiated Ground-Burst EMP Waveform. From J. A. Northrop 1996 EM-1

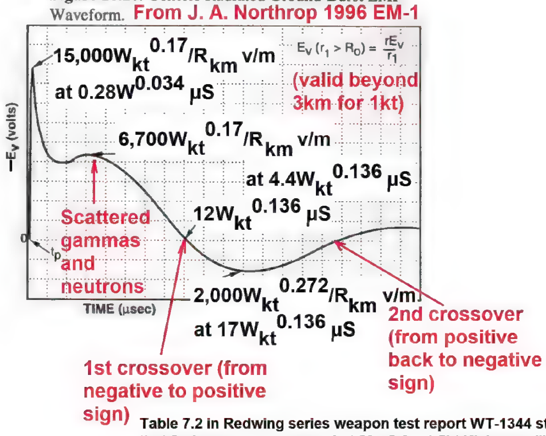
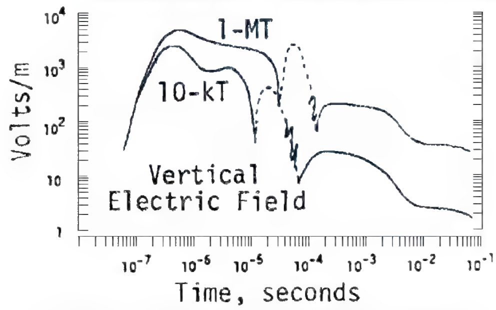


Table 7.2 in Redwing series weapon test report WT-1344 states that 2nd crossover occurred at 29 μS for 1.5kt Kickapoo (linear implosion Swallow), 50 for 1.9Mt Apache and 70 for 4.5Mt Navajo

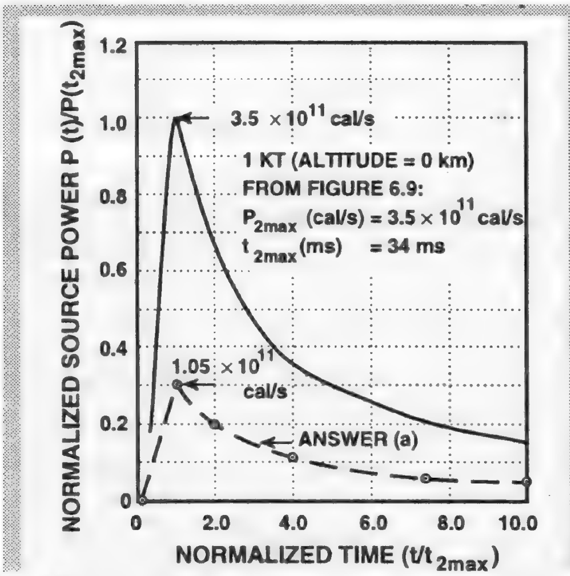


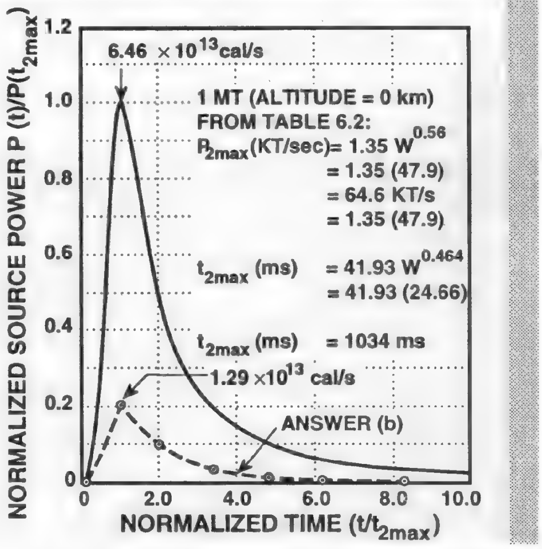
C. L. Longmire, "History and Physics of EMP," presentation at the Fourth NEM Symposium, Baltimore, Maryland, July 2, 1984.

Edgerton, Germeshausen and Grier, Inc., Boston, Mass.
ELECTROMAGNETIC EFFECTS FROM NUCLEAR TESTS (U), by B. J. Stralser. 30 Apr 61. 68p. incl. illus. (EG&G rept. no. L-523) (DASA-1226) Secret report
Formerly Restricted Data.

Table 6.1. Thermal Fraction Values for Near-Surface Bursts.

	RECIPE			RADFLO	
Yield (KT)	Surface Burst Thermal Fraction	Nonsurface Burst Thermal Fraction	Transition Height (meters)	Surface Burst Thermal Fraction	Nonsurface Burst Thermal Fraction
1	0.045	0.35	4	.149	.350
10	0.066	0.34	8.6	.157	.350
100	0.13	0.33	18.5	.166	.350
1,000	0.16	0.31	40	.176	.350
10,000	0.17	0.26	86	.186	.350





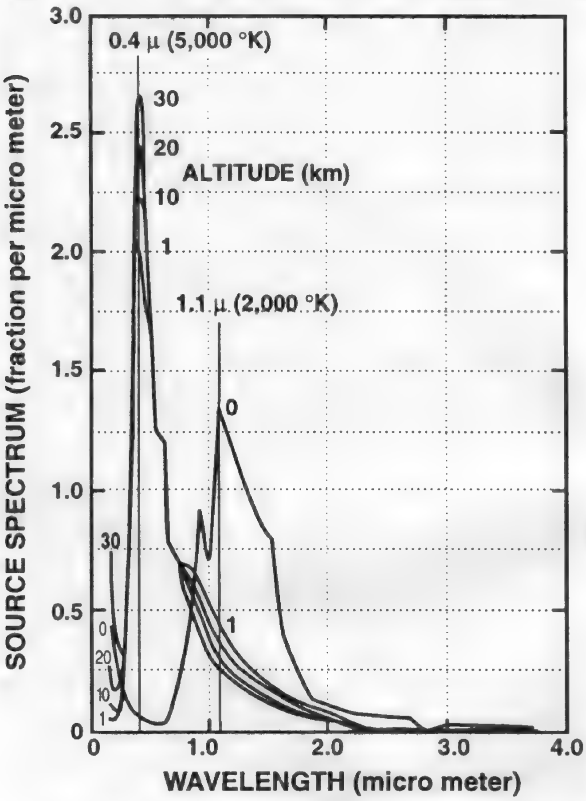


Figure 6.19. Effects of Altitude on Spectral Distribution for a 1-KT Burst.

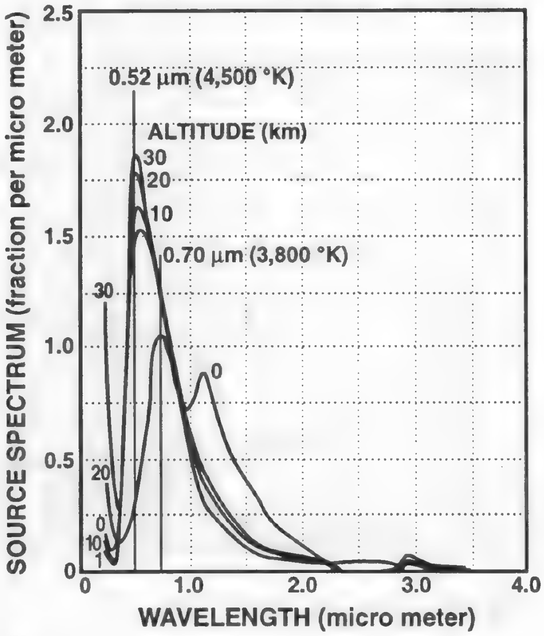
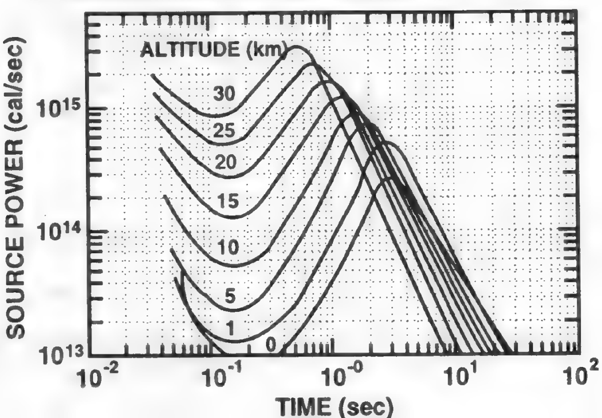


Figure 6.21. Effect of Altitude on Spectral Distribution for a 1-MT Burst.

Figure 6.13. Effects of Altitude on Thermal Power for a 10-MT Burst.



6.3 Atmospheric Transmission Effects. As introduced in Equation 6.1, transmission effects are given by the product Tg, where T is the transmittance factor for a generalized geometry with idealized albedo surfaces and model atmospheres depending on the visibility. The geometry factor g includes fireball asymmetry and target orientation effects. Values of T and g have been computed for a wide variety of situations and are presented in graphical form for predictive purposes. Such predictions are intended only to bracket a particular case for which actual transmission factors will vary with time and space, and may be very difficult to specify quantitatively. In addition, the normal variables of humidity, dust, haze, fog, smog, and albedo factors will be even less predictable in rapidly changing wartime environments.

The codes used to produce these data compute both the direct and scattered components as a function of wavelength over the range between 0.3 and 4.0 μm. Scattering includes both Rayleigh (molecular) and Mie (aerosol), and absorption is calculated for water vapor, carbon dioxide, and ozone. The cross sections for all of these processes are wavelength dependent.

Thus, it is customary to define discrete wavelength bands and perform the transport calculations with the scattering and absorption parameters defined over the separate bands. The "buildup factor" is the ratio of the total exposure to directly transmitted exposure, and thus is a measure of the importance of the scattered or diffuse component of the radiation. Figure 6.38 illustrates this factor as a function of optical depth (integral of the product of the scattering cross section and number density of the scattering medium along the path from source to detector) for Pacific Test Site conditions and the albedo of seawater, and shows that the diffuse component may be much larger than the direct component at long ranges. The resulting angular distribution for one wavelength (0.55 μm) is shown in Figure 6.39.

6.3.1 Effects of Meteorological Conditions. This section considers the effects of aerosols and molecular absorption. Albedo effects will be discussed in Section 6.3.2.

6.3.1.1 Visibility. Daylight visibility is the distance at which a large dark object is just recognizable against the sky background. Nighttime visibility is defined as the longest distance at which an unfocused light of moderate intensity can be seen. Table 6.3 gives the international visibility code, relating a qualitative description of the atmosphere to observed visibilities. It is usually assumed that the transmittance is 5.5 percent along the distance corresponding to the visibility.

The "meteorological range" (MR) is the horizontal distance for which the transmittance of the atmosphere for a direct beam of light is 2 percent. The meteorological range is related to the atmospheric extinction cross section by:

$$\sigma_T = 3.91/MR \qquad (6.8)$$

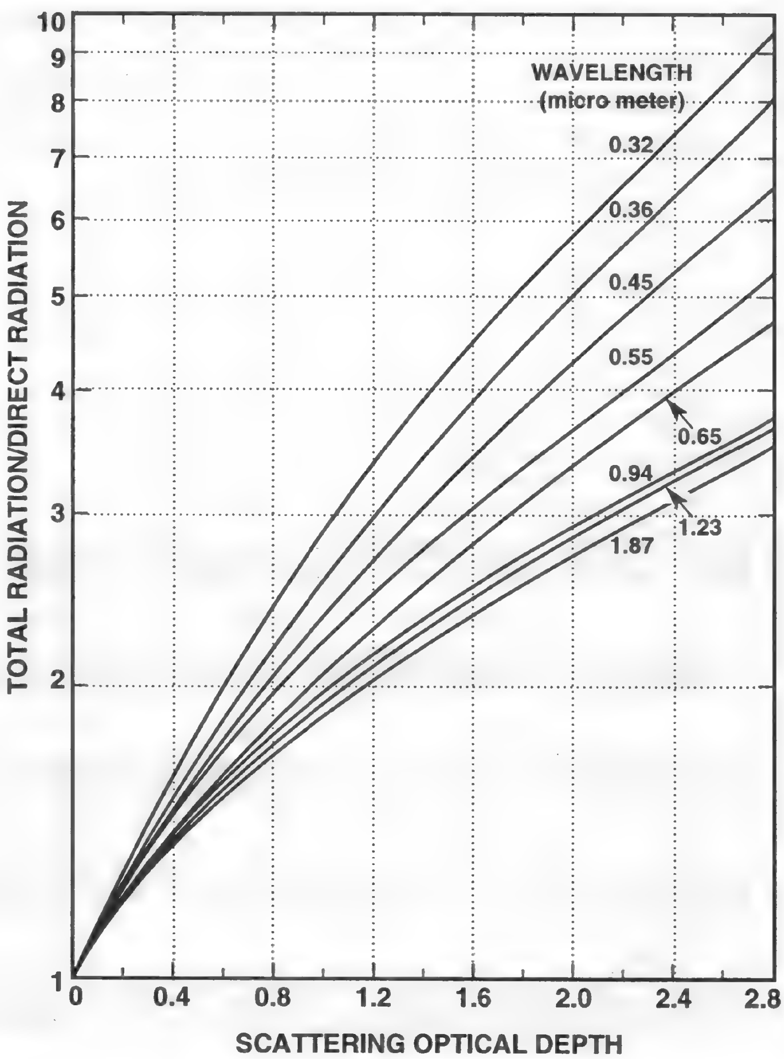


Figure 6.38. Comparison of Buildup Factors for Various Radiation Wavelengths Simulating Pacific Atmosphere with Both Source and Sampling at 1-km Altitude.

The relationship between the visibility and the meteorological range is:

$$V = 0.74\ MR\ . \tag{6.9}$$

In this section, all transmission predictions will be related to the visibility, and not to the meteorological range.

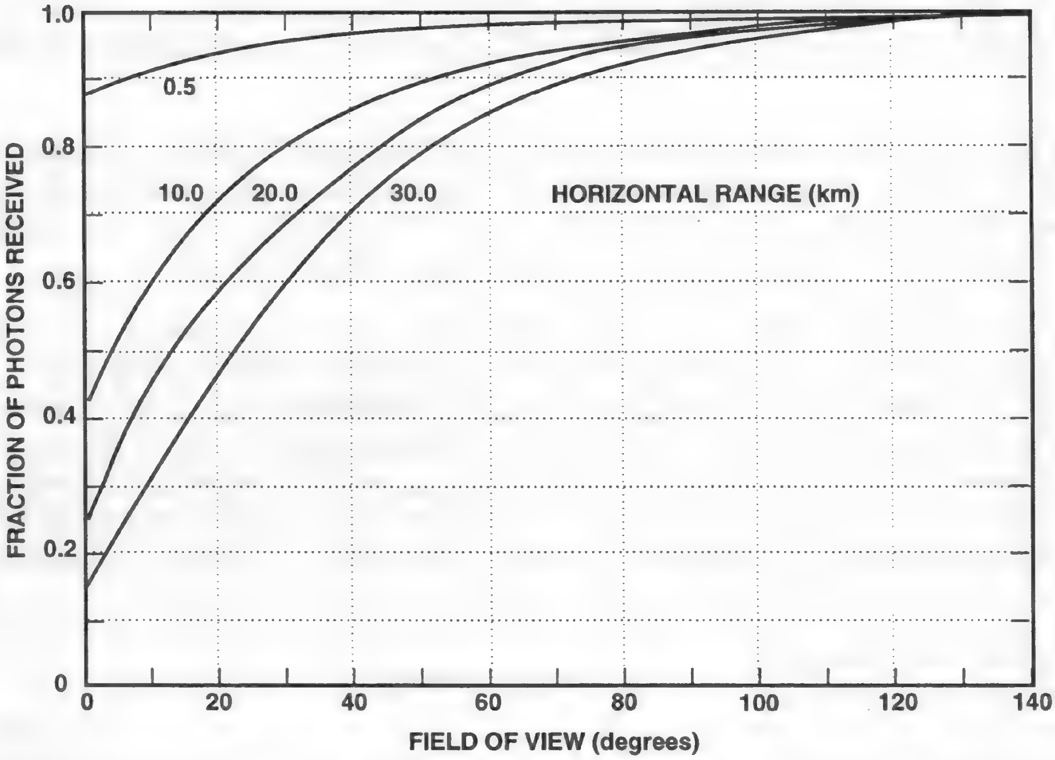


Figure 6.39. Effects of Field of View on the Thermal Radiation for a Target on the Ground from a 0.55 μm Source at an Altitude of 1 km.

Table 6.3. International Visibility Code.

Code Number	Description	Visibility From		Visibility To	
0	Dense Fog	—	—	50 meters	(55 yards)
1	Thick Fog	50 meters	(55 yards)	200 meters	(220 yards)
2	Moderate Fog	200 meters	(220 yards)	500 meters	(550 yards)
3	Light Fog	500 meters	(550 yards)	1 km	(0.6 mile)
4	Thin Fog	1 km	(0.6 mile)	2 km	(1.2 miles)
5	Haze	2 km	(1.2 miles)	4 km	(2.5 miles)
6	Light Haze	4 km	(2.5 miles)	10 km	(6 miles)
7	Clear	10 km	(6 miles)	20 km	(12 miles)
8	Very Clear	20 km	(12 miles)	50 km	(30 miles)
9	Exceptionally Clear	50 km	(30 miles)	—	—

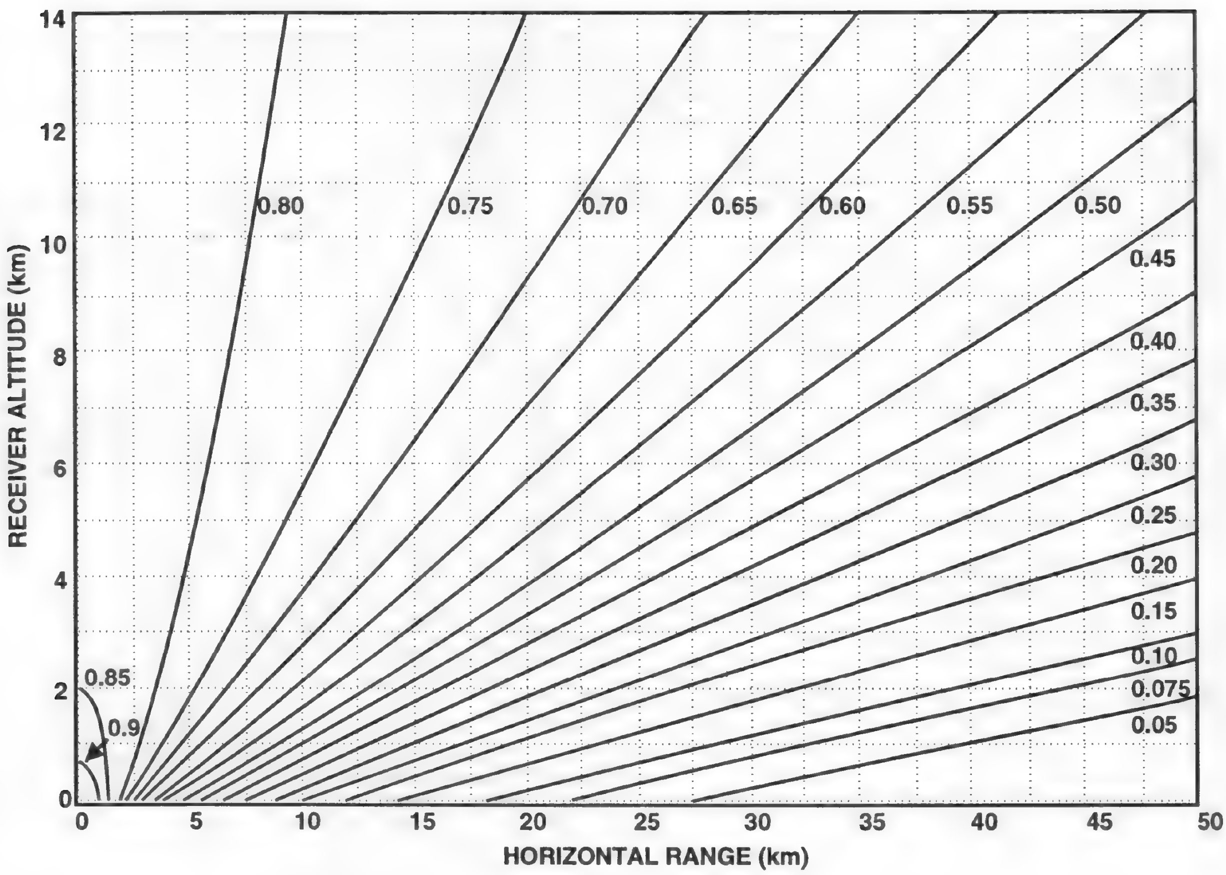


Figure 6.46. Transmission Contours for a 10-MT Surface Burst with a Visibility of 10 km.

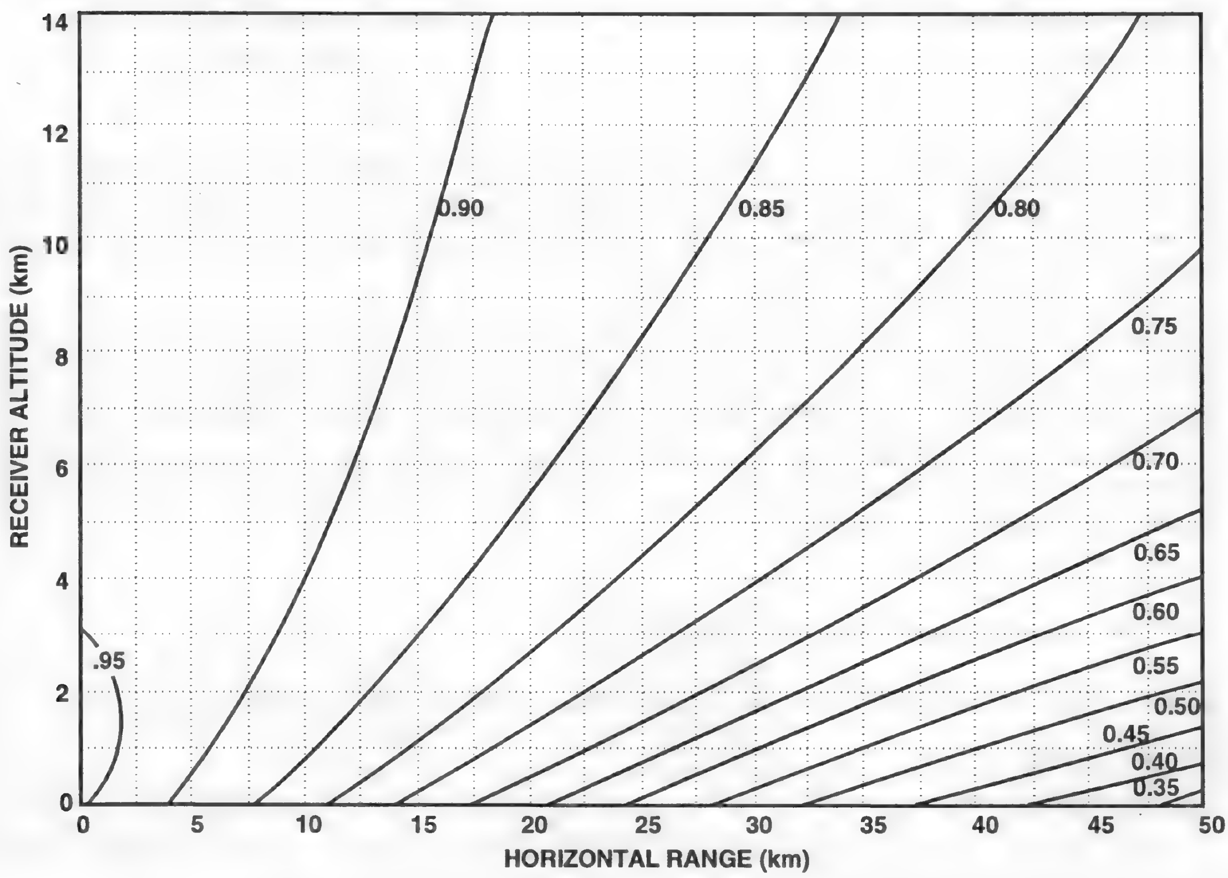


Figure 6.47. Transmission Contours for a 1-MT Burst at an Altitude of 1 km with a Visibility of 50 km.

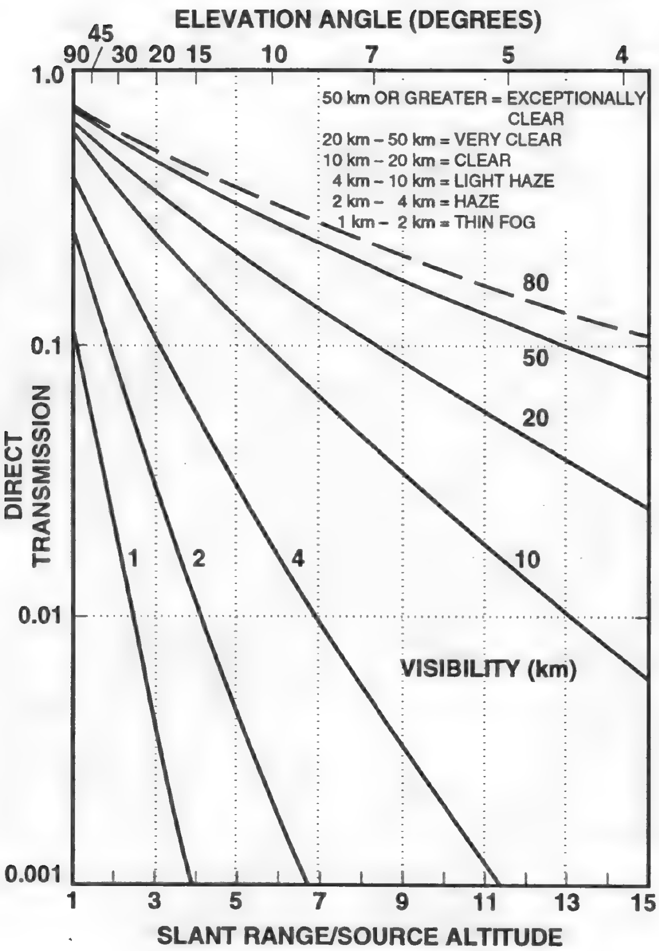


Figure 6.48(a). Transmission from a High-Altitude Burst to a Target on the Ground Surface (Direct).

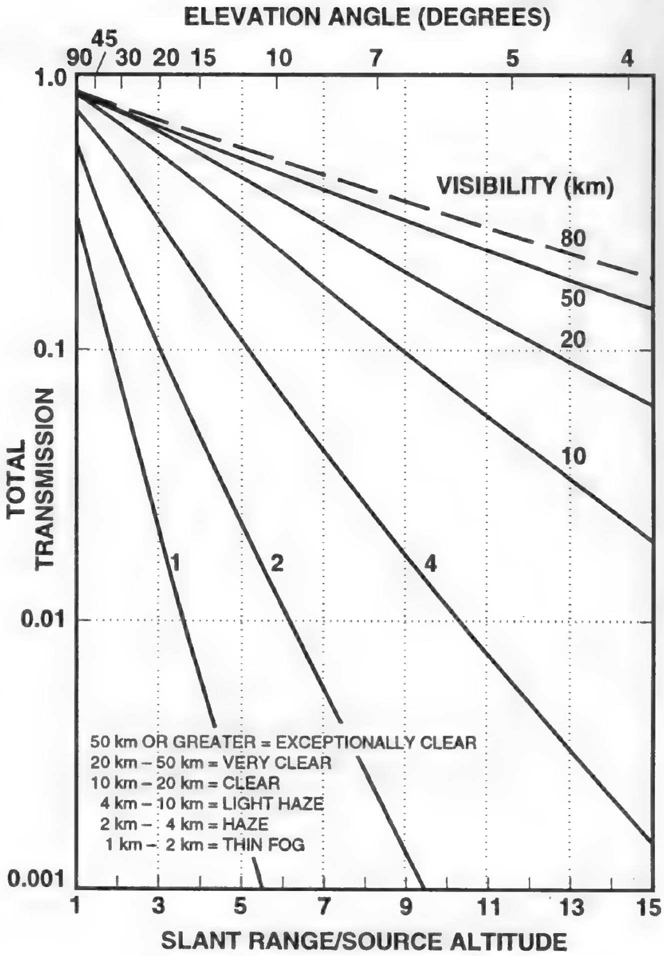


Figure 6.48(b). Transmission from a High-Altitude Burst to a Target on the Ground Surface (Total).

Monte Carlo calculations are required when atmospheric transmission effects are included with the albedo calculations. *EM-1* contains figures showing the results of a series of such calculations for a 1-MT burst at 1-km altitude in a 50-km visibility, for various combinations of albedo surfaces. It is not feasible to interpolate to other parameter sets.

However, a generalized data set is available for the case in which atmospheric effects are neglected and a diffuse reflecting plane has an albedo of unity. In Figure 6.52, A_1 and S_1 are the target altitude and the horizontal range of the detector normalized by the source altitude. The quantity plotted is the sum of the direct component and that due to the albedo surface. The target orientation was chosen to maximize the exposure but is essentially aimed at the source. The transmission for an albedo (ρ) less than unity can be approximated by:

$$T_\rho = 1 + \rho(T_1 - 1)\,, \tag{6.12}$$

where T is the transmission for an albedo of unity.

For a surface burst with a hemispherical fireball on the albedo surface, the transmission is,

$$T_\rho = 1 + \rho\gamma_n/\eta_n\,. \tag{6.13}$$

where the functions γ_n and η_n are given in Figures 6.53(a) and 6.53(b), respectively. In these figures, R is the slant range to the target, R_s is the radius of the hemispherical fireball, and θ is the angle between a vertical line through the burst point and the line of sight to the target.

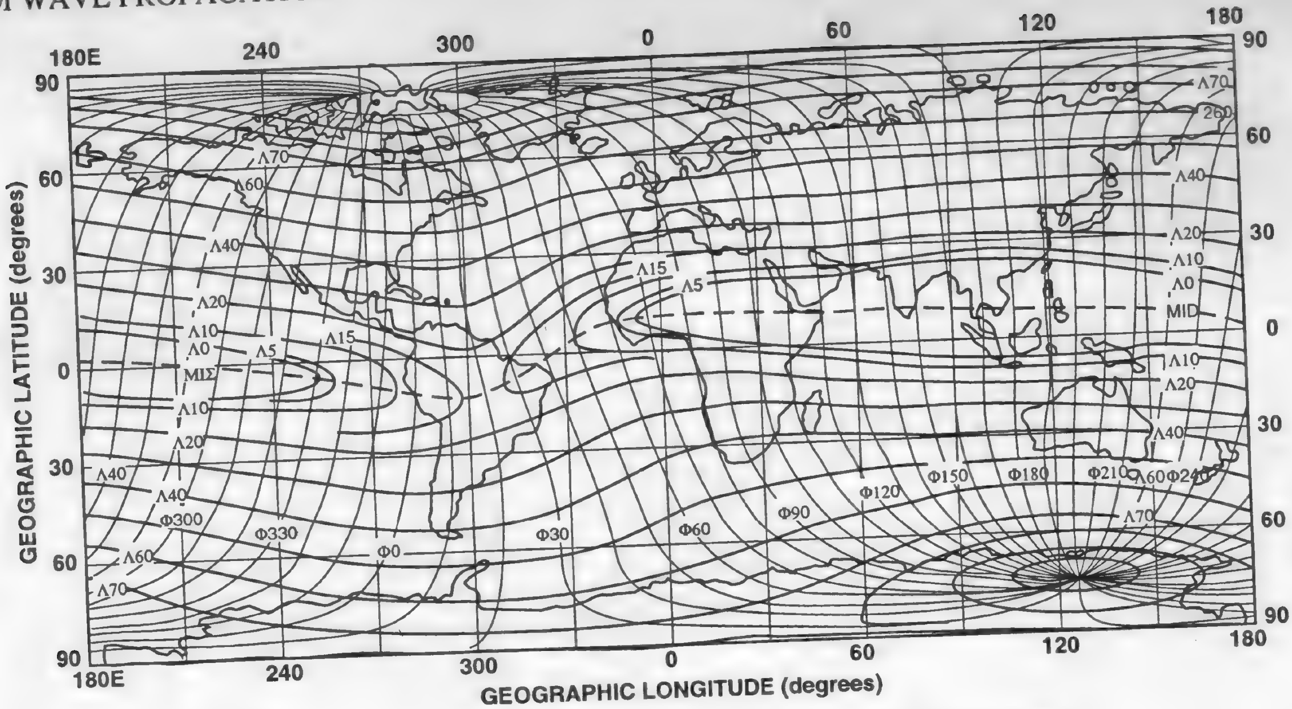


Figure 9.3. World Map of Geomagnetic Coordinates at 0 km Altitude.

emitted promptly (within a microsecond); about 5 to 10 percent is delayed radiation (gamma rays and beta particles) from decay of fission debris.

"Stopping altitudes" for the principal radiations from a nuclear weapon are shown in Table 9.1. These are the altitudes for radiation entering the atmosphere from above the altitude where mass penetrated equals the reciprocal of mass absorption coefficient. For detonations below the stopping altitude of a particular radiation, most of that radiation will be contained locally. When detonations occur above the stopping altitude of a particular radiation, that radiation can spread over large distances before being deposited and causing ionization. About 3×10^4 ion pairs are produced for each MeV of energy deposited in the atmosphere. About 3×10^{28} MeV are released per megaton of weapon yield.

9.1.2.1 Electron Density Within the Fireball. At altitudes below about 80 km, fireballs can be considered approximately homogeneous, with electron densities depending on burst altitude, yield, and time after burst. For detonations above about 100 km, electron densities vary greatly over the region of the fireball and the earth's magnetic field strongly influences debris motion and thus fireball shape. Figure 9.4 shows electron densities for a nominal 1 MT burst at four altitudes as a function of time, with accompanying sketches of fireball rise and expansion. For the 250 km burst, the density shown is the maximum, near the bottom of the rather non-homogeneous and dispersed fireball.

Figure 9.5 shows contours of mean electron density for a 1-MT burst at 250 km. The contours are shown on the meridian plane of a magnetic dipole coordinate system. The dipole coordinates α and β are related to magnetic spherical coordinates by:

$$\cos\alpha = (R_e/R)^2 \cos\theta\,, \tag{9.3}$$

$$\sin\beta = (R_e/R)^{1/2} \sin\theta\,, \tag{9.4}$$

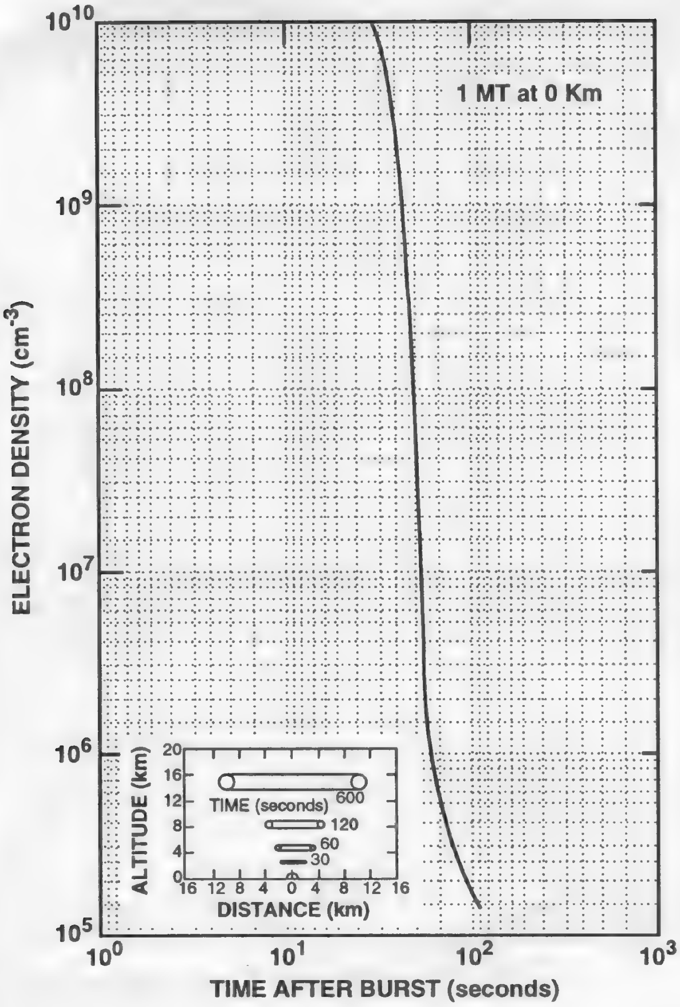
where θ = geomagnetic colatitude, and R_e = earth's radius.

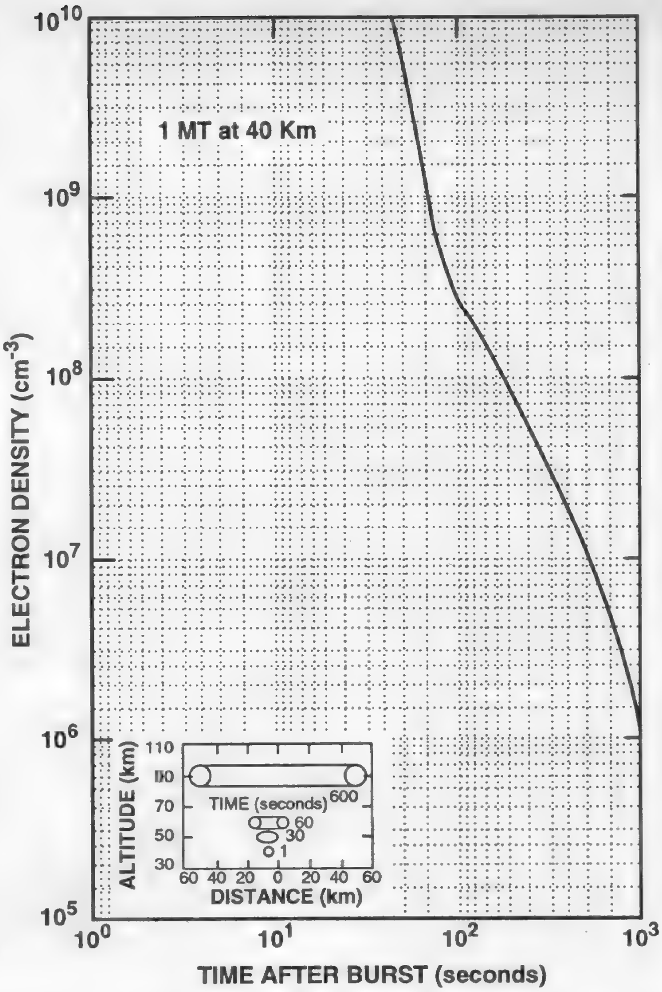
Lines of constant β are dipole field lines and lines of constant α are orthogonal to the field lines. The β-coordinate is related to the geomagnetic shell parameter L by:

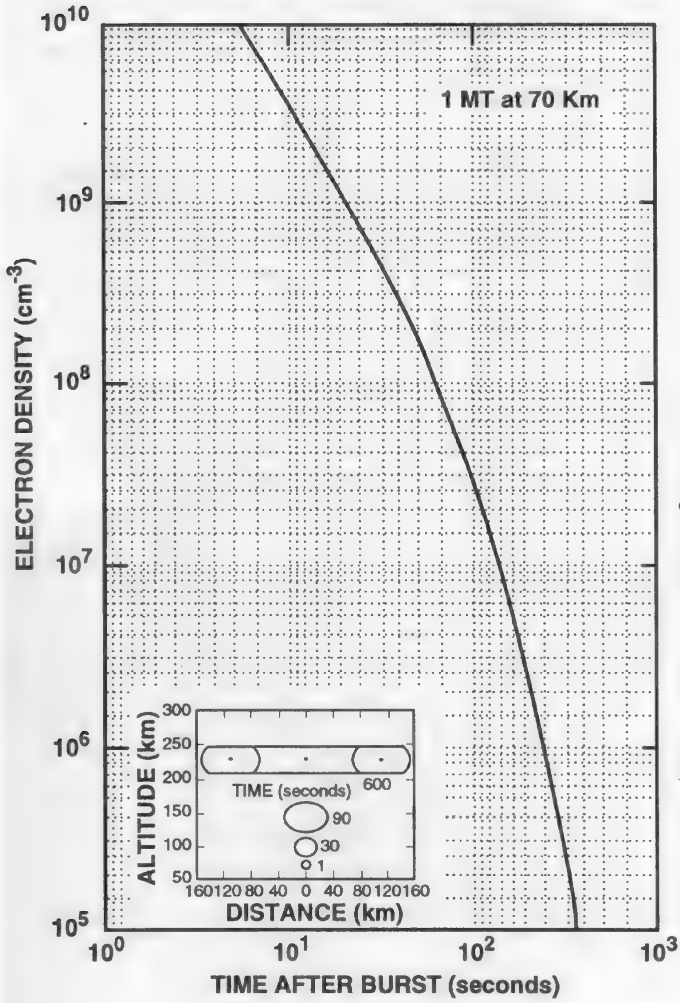
$$\beta = \sin^{-1}(L^{1/2})\,, \tag{9.5}$$

Table 9.1. Approximate Stopping Altitudes for Principal Weapon Outputs Causing Ionization.

Weapon Output	Stopping Altitude (km)
Prompt Radiation	
X rays (1-keV radiator)	80
Neutrons	25
Gamma rays	25
Debris (kinetic energy)	115
Delayed Radiation	
Gamma rays	25
Beta particles (1 MeV)	60







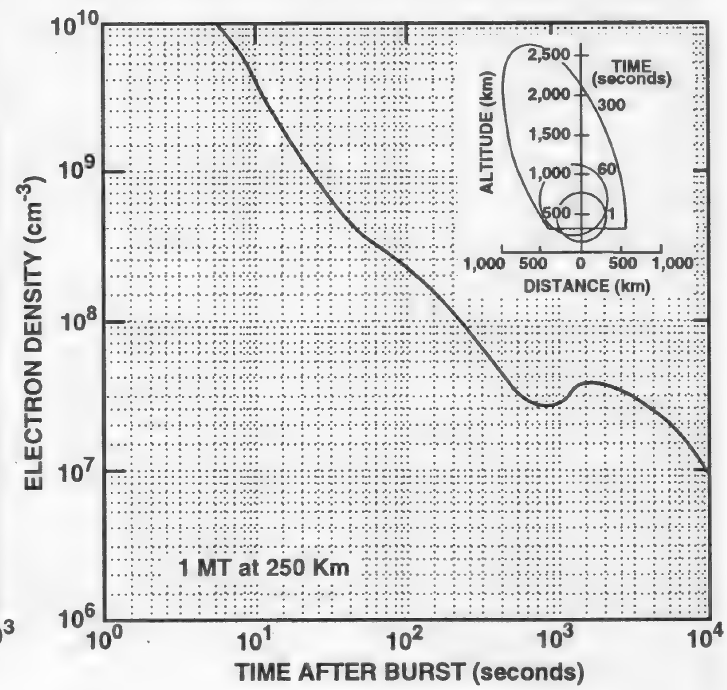
Figures arranged clockwise starting upper left:

Figure 9.4a. Fireball Electron Density, 1 MT at 0 km.

Figure 9.4b. Fireball Electron Density, 1 MT at 40 km.

Figure 9.4c. Fireball Electron Density, 1 MT at 70 km.

Figure 9.4d. Fireball Electron Density at a Point Near the Bottom of the Fireball, 1 MT at 250 km.



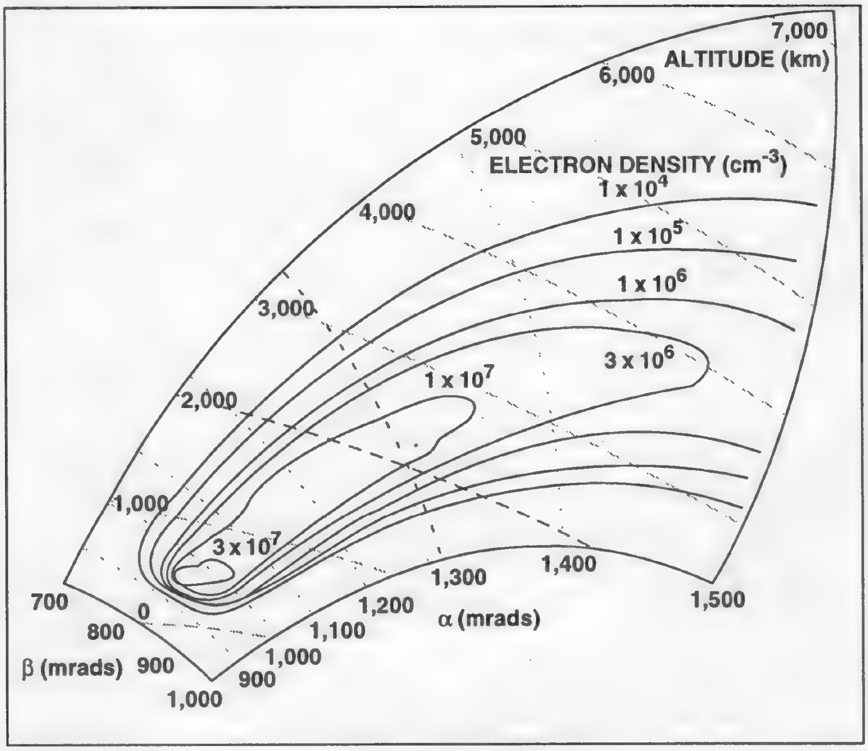


Figure 9.5. Electron Density Contours in Magnetic Meridian Plane, 1 MT at 250 km, t = 1,000 seconds.

where $L = R_0/R_e$ and

R_o = distance from the field line at the magnetic equator to the center of the earth.

9.1.2.2 Electron Density Outside the Fireball Caused by Prompt Radiation. For bursts below 25 km, prompt radiation outside the fireball is insignificant. Between 25 and 80 km altitude, neutrons produce ionization over several hundred km, but the gamma ray contribution is insignificant. Above 80 km, x rays cause widespread ionization and debris kinetic energy contributes for bursts above about 115 km.

Figure 9.6 shows the initial ionization caused by prompt radiation from a nominal megaton weapon detonated at 120 km. Below about 100 km, the electron and ion density after 1 second will be essentially independent of the initial ionization if it is greater than 10^7 ion pairs/cm^3, termed "saturation." Figure 9.7 shows the altitude dependence of the electron density for several times after a saturation impulse. The inset illustrates the horizontal extent of the region that can be saturated by prompt radiation as a function of detonation altitude.

Figure 9.8 shows the initial fireball region and the E- and F-region ionization outside the fireball caused by prompt radiation for a 1-MT burst at 250 km. The fireball is produced by the deposition of debris kinetic energy in the atmosphere. Some of the debris kinetic energy can escape the fireball as ultraviolet radiation produced as the fireball is formed, and some as heavy-particle kinetic energy. The x-ray and ultraviolet ionization regions are symmetrical about the burst point, while the heavy-particle ionization is confined by the geomagnetic field and is more localized and more highly ionized.

Prompt energy deposition above about 90 km can heat as well as ionize the air, causing atmospheric heave. The prompt ionization regions outside the fireball above 100 km can become striated, with onset times of tens of minutes. Neutron decay (half-life 12 minutes) beta particles can produce weak, but observable, ionization at the geomagnetic conjugate point.

9.1.2.3 Electron Density Outside the Fireball Caused by Delayed Radiation. Delayed gamma rays and beta particles from fission debris produce ionization characterized by a production rate of ion pairs per unit volume per unit time. For detonation below several hundred kilometers, the fission debris is initially within the fireball and is carried upward and expands with the fireball.

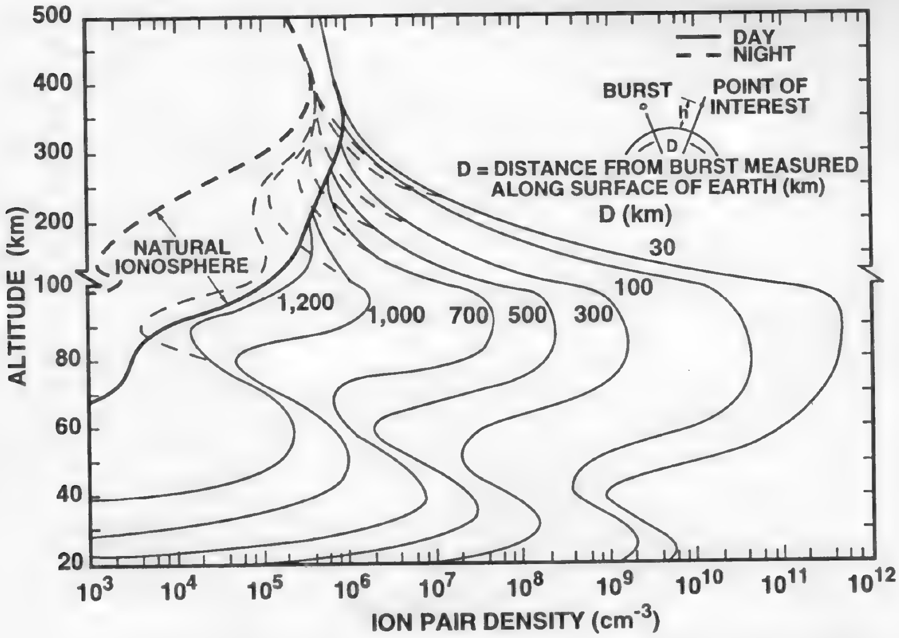


Figure 9.6. Ion-Pair Density Due to Prompt Radiation from a 1-MT Burst Detonated at 120 km, t = 0.

Gamma Rays. Debris gammas emitted below their stopping altitude (25 km) form a local ionization region around the fireball that can affect fireball thermal emission and EM energy scattering. Above this altitude, most gamma-ray energy is deposited near the stopping altitude, but maximum electron density usually occurs at higher altitudes where the electron lifetimes are longer. Figure 9.9 shows electron density contours for debris at 30 km, in which the persistence of ionization at the altitude of the D-region is evident.

When the fission debris and the point of interest are both well above the gamma-ray stopping altitude, the ion-pair production rate and electron and ion densities caused by gamma rays can be expressed conveniently in terms of a radiation intensity parameter I_γ, defined by:

$$I_\gamma = (3.2 \times 10^6 \, W_F/R^2(1 + t)^{1.2}) \text{ W/m}^2 , \tag{9.6}$$

where W_F = fission yield (MT)

R = radial distance from debris center to point of interest (km)

t = time after detonation (seconds).

Figure 9.10 shows quasi-equilibrium electron densities for particular values of I_γ. They are the values that would be reached if the production rate remained constant and if sufficient time were allowed for equilibrium conditions to be reached. The inset in Figure 9.10 illustrates the horizontal extent as a function of debris altitude for which the electron densities are applicable.

Beta Particles. Below the beta-particle stopping altitude, beta particles form an electron-ion sheath around the debris region which will have similar optical absorption effects and EM-wave scattering as described for gamma-rays. When debris occurs at higher altitudes, significantly above the beta stopping altitude, beta particles will follow EM field lines and create ionization, both below the debris and at the conjugate point, at the beta stopping altitude. Each of these areas will be surrounded by a somewhat larger area of Compton electron ionization. The ion-pair production rate and electron density caused by beta particles can be expressed conveniently in terms of a radiation intensity parameter N_β defined by:

$$N_\beta = 8.8 \times 10^{15} \, W_F \,/\, [A(1 + t)^{1.2}] \text{ betas/cm}^2\text{-sec}^{1.2} , \tag{9.7}$$

where A = area covered by fission debris in square kilometers.

Figure 9.11 shows the quasi-equilibrium electron density caused by beta particles for particular values of N_β. These curves apply if the fission debris is well above the beta stopping altitude and if the debris is uniformly distributed over the area A.

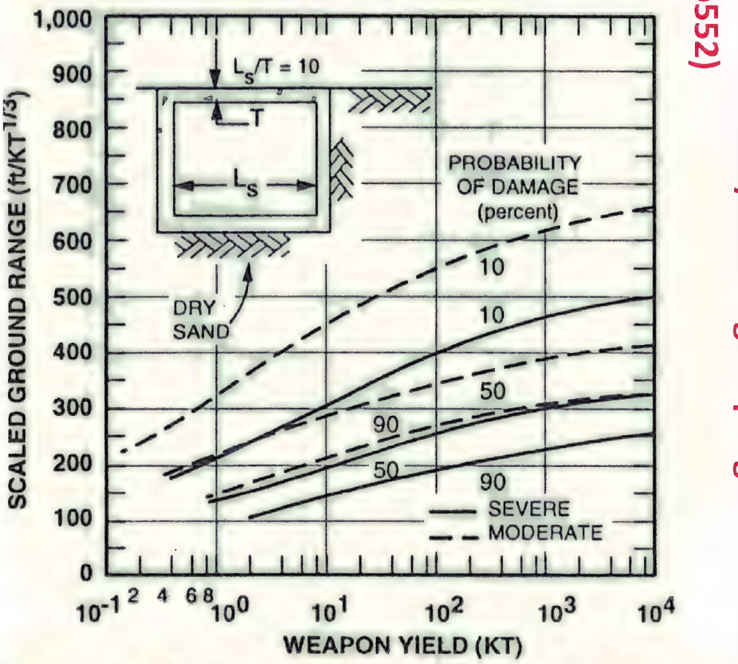


Figure 15.43. Vulnerability Curves for a Flat-Roofed Structure, Aspect Ratio $L_s/T = 10$ (Structure Category 15.3.11) Surface-Flush in Dry Sand.

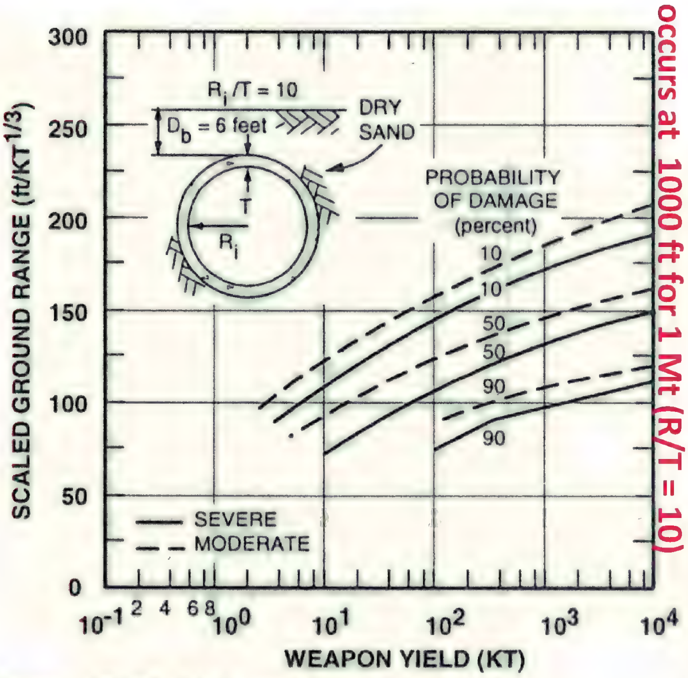


Figure 15.52. Vulnerability Curves for a Horizontal Cylinder, Aspect Ratio $R_i/T = 10$ (Structure Category 15.3.18) Buried in Dry Sand.

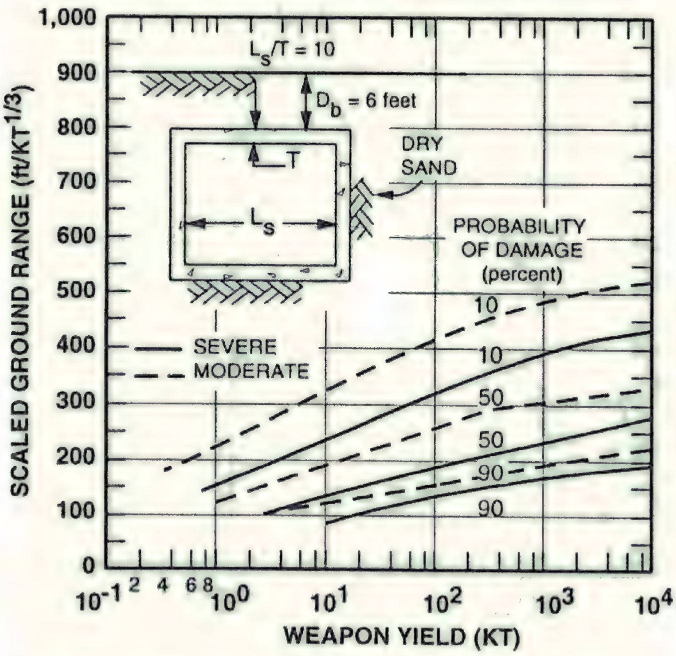


Figure 15.35. Vulnerability Curves for a Flat-Roofed Structure, Aspect Ratio $L_s/T = 10$ (Structure Category 15.3.3) Buried in Dry Sand.

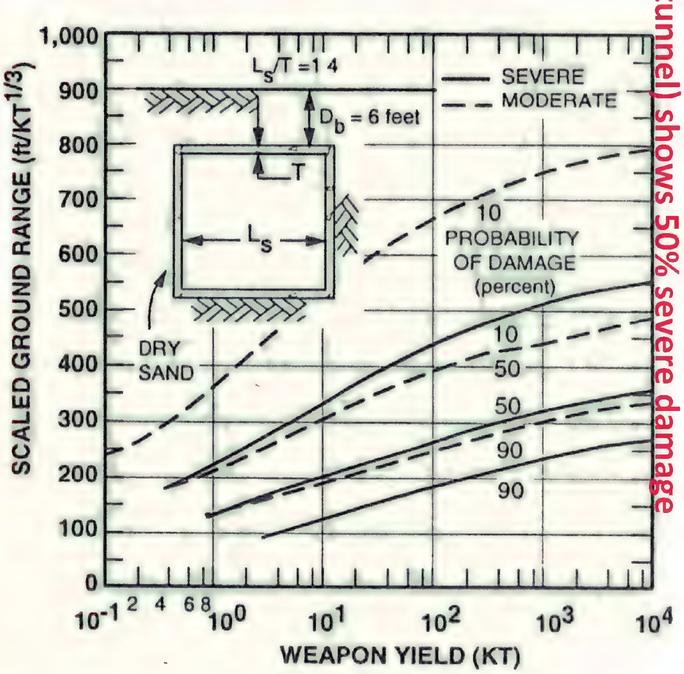


Figure 15.36. Vulnerability Curves for a Flat-Roofed Structure, Aspect Ratio $L_s/T = 14$ (Structure Category 15.3.4) Buried in Dry Sand.

4500 psi concrete strength. Fig 15.60 for a vertical silo (tunnel) shows 50% severe damage occurs at 1000 ft for 1 Mt (R/T = 10)

Data from two underground tests of different yields, converted to surface bursts on the assumption that the ground shock/cratering coupling for the surface burst is 5% that for underground bursts (Northrop, 1996, p552)

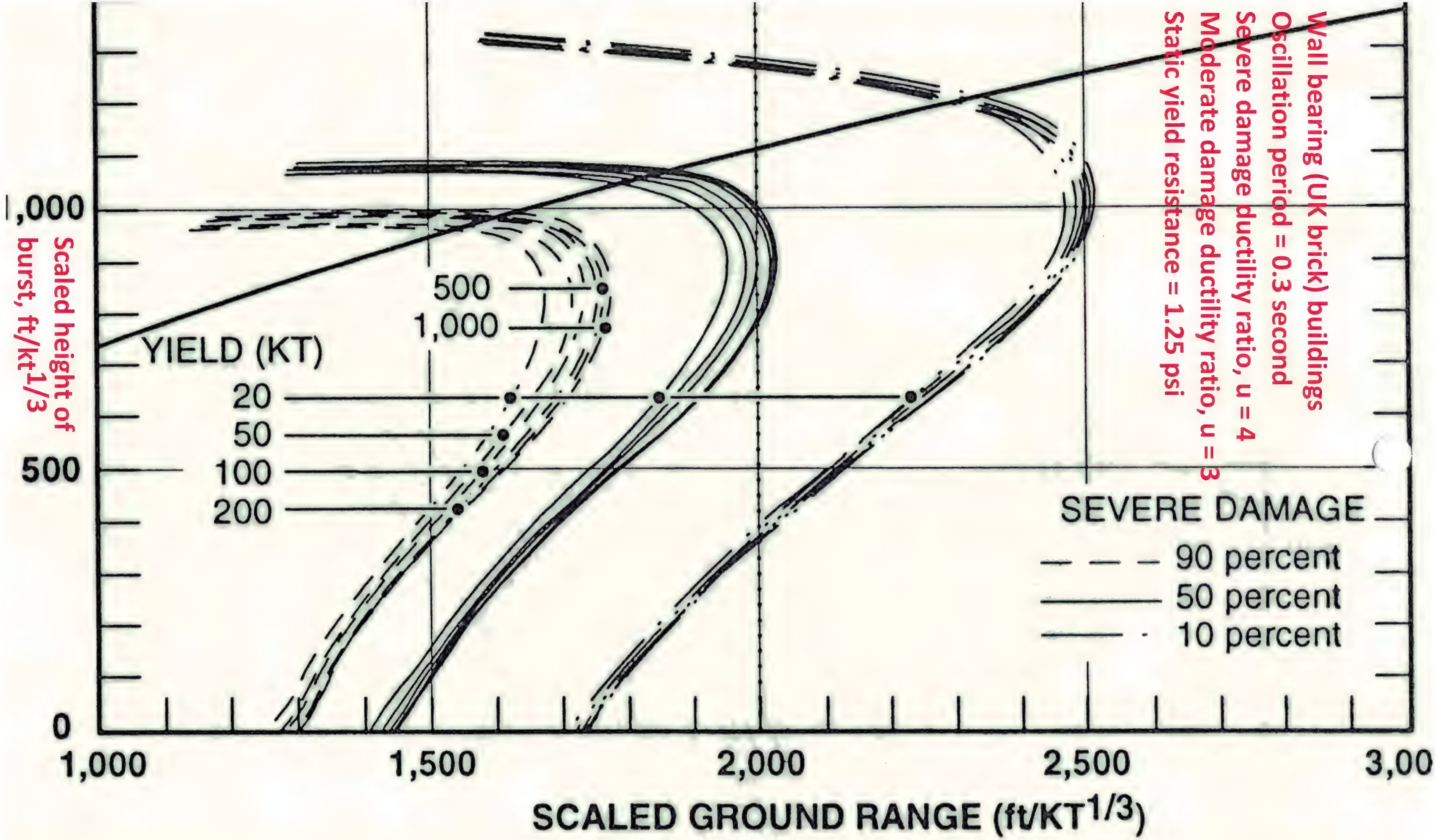


Figure 15.11. Moderate and Severe Isodamage Curves for Structure Category 15.2.3 for Yields Ranging From 20 KT to 1,000 KT.

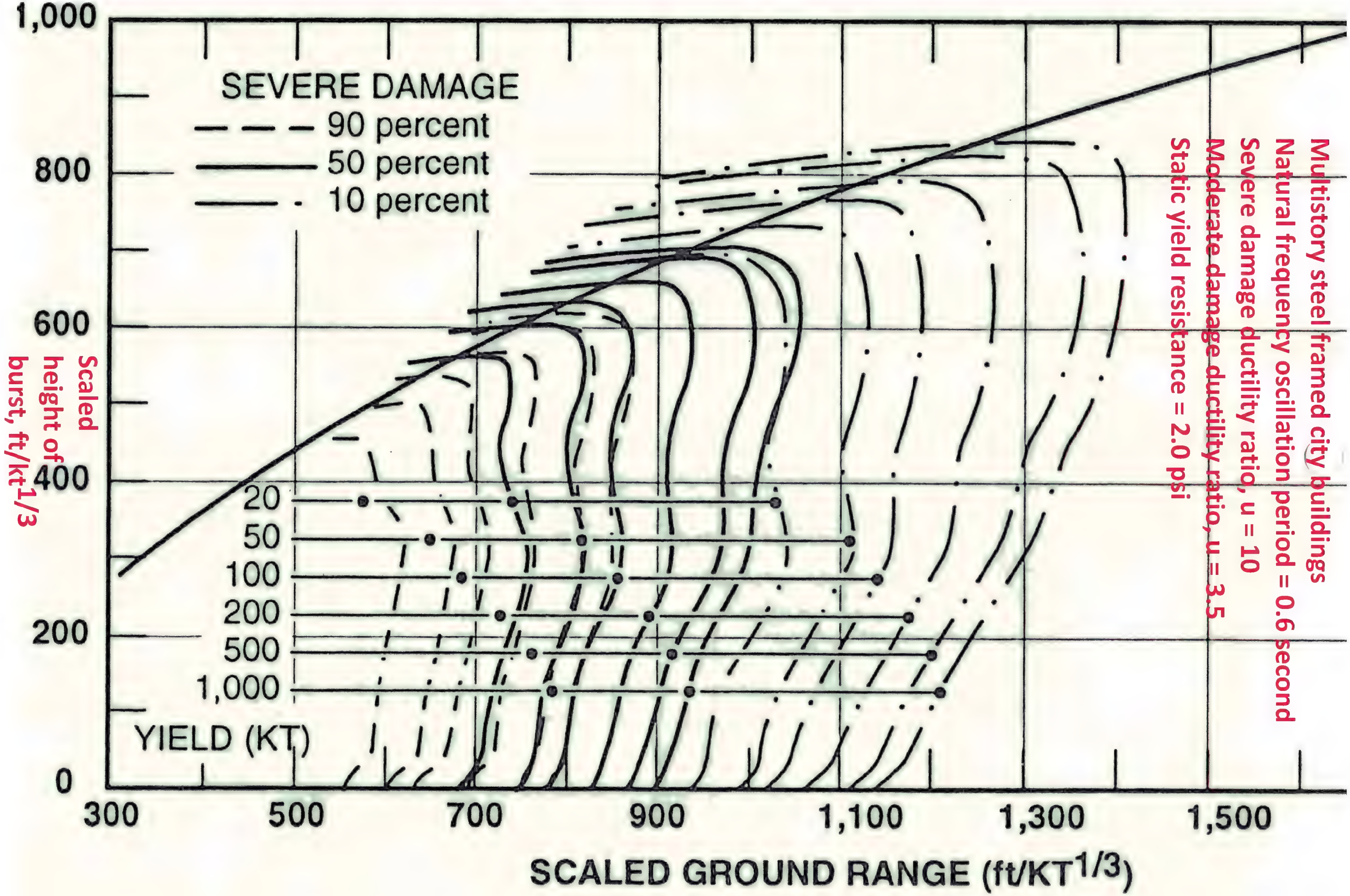


Figure 15.18. Moderate and Severe Isodamage Curves for Structure Category 15.2.10 for Yields Ranging From 20 KT to 1,000 KT.

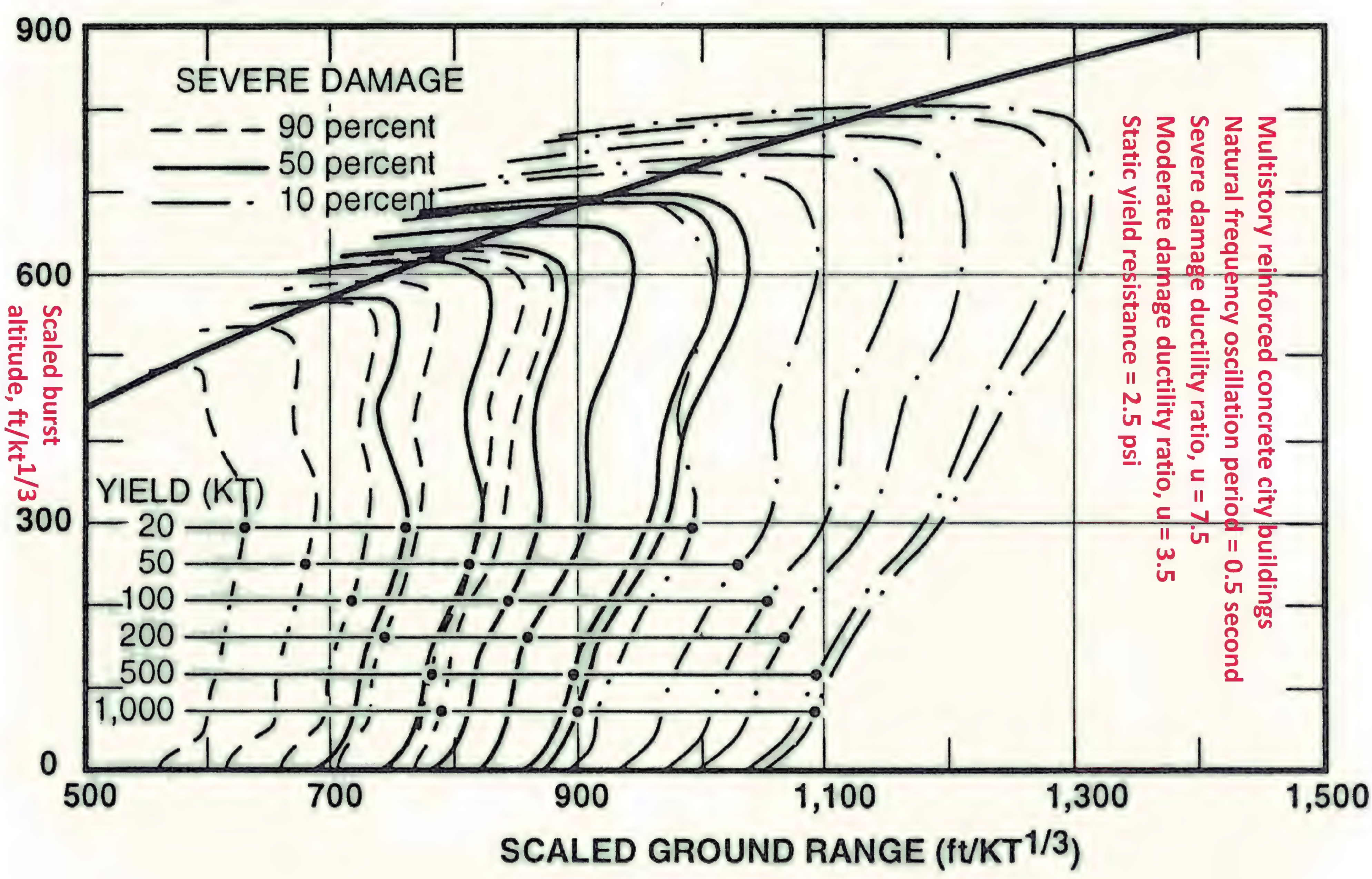
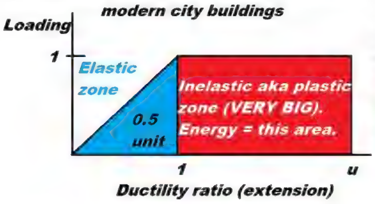


Figure 15.20. Moderate and Severe Isodamage Curves for Structure Category 15.2.12 for Yields Ranging From 20 KT to 1,000 KT.

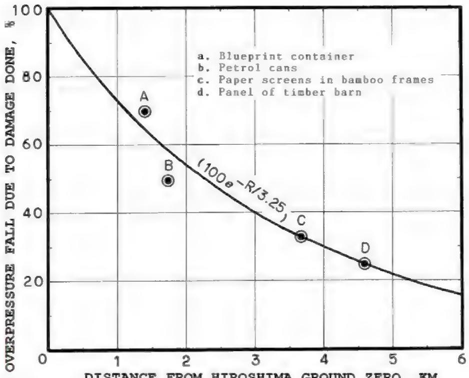
EM-1: ratio of energy to flatten vs. oscillate modern city buildings



Total blast wave energy absorbed by a city building, divided into the blast energy that can be absorbed to merely oscillate (in the elastic zone) a building = blue plus red areas, divided into blue area

= [0.5 + (u - 1)] / 0.5

= 1 + 2(u - 1)



Data from Dr W. G. Penney, et al., 'The Nuclear Explosive Yields at Hiroshima and Nagasaki', Phil. Trans. Roy. Soc., v266 (1970), pp. 357-424.

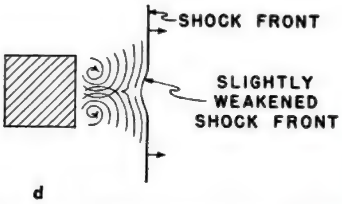
total blast energy — dynamic pressure — overpressure

$$E = 4\pi \int_0^R \left(\frac{1}{2} \rho u^2 \right) r^2 \, dr + 4\pi \int_0^R \frac{p}{\gamma - 1} r^2 \, dr$$

KINETIC ENERGY — **INTERNAL ENERGY**

The Effects of Atomic Weapons

PREPARED FOR AND IN COOPERATION WITH THE U. S. DEPARTMENT OF DEFENSE AND THE U. S. ATOMIC ENERGY COMMISSION



igure 5.3. Behavior of blast wave upon striking cubical structure: (*a*) before striking the structure; (*b*) soon after striking the structure; (*c*) soon after passing the structure; (*d*) wave completely past the structure.

GENERAL CONSIDERATIONS

3.20 In the preceding paragraphs, the discussion has dealt with the air blast from an atomic bomb exploded in an infinite atmosphere. In this section consideration will be given to the influence of the height of burst of the bomb on the area of blast damage. The problem is extremely complex and can be solved only in a statistical or average manner. This is so for two reasons: first, the detailed description of a military target can never be completely given, and second, the complete analytical solution of even such a relatively simple problem as the behavior of a shock wave incident on a wall at an oblique angle has never been obtained for all angles. As will be seen later, a solution of the basic problem of shock reflection from a rigid wall can be derived by a combination of theory and experiment. This solution is, however, not readily adapted to yielding the effect of blast in better than an average sense in a more complicated situation. As to the detailed description of the target, not only are the structures of odd shape, but they have the additional complicating property of not being rigid. This means that they do not merely deflect the shock wave, but they also absorb energy from it at each reflection.

3.21 The removal of energy from the blast in this manner decreases the shock pressure at any given distance from the point of detonation to a value somewhat below that which it would have in the absence of dissipative objects, such as buildings. The presence

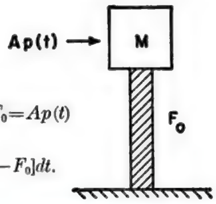
[11] This section is based on work by J. von Neumann and F. Reines done at the Los Alamos Scientific Laboratory.

58 SHOCK FROM AIR BURST

of such dissipation or diffraction makes it necessary to consider somewhat higher values of the pressure than would be required to produce a desired effect if there were only one structure set by itself on a rigid plane.

APPENDIX A[1]

AN APPROXIMATE METHOD OF COMPUTING THE DEFORMATION OF A STRUCTURE BY A BLAST WAVE



$$M\frac{d^2x}{dt^2}+F_0=Ap(t)$$

$$v=\frac{1}{M}\int_0^t [Ap(t)-F_0]dt.$$

Figure A.2. Mass supported on plastic spring equivalent to single-story structure.

Glasstone's 1950 *Effects of Atomic Weapons* explained the basis of blast attenuation clearly.

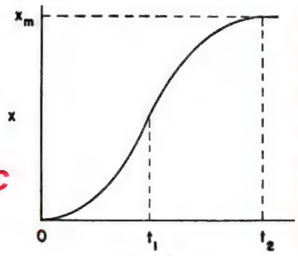


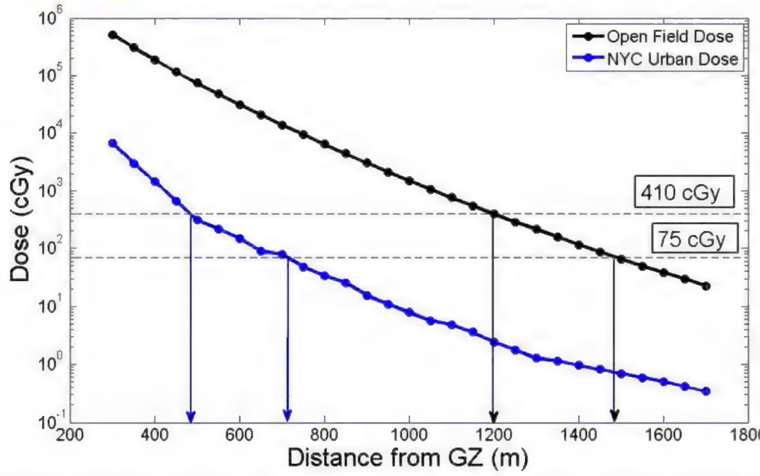
Figure A.5. Displacement of center of mass as function of tim

Glasstone's 1950 Appendix A calculates deflection of building, allowing energy absorbed to be calculated from: $E = \int F\,dx = \int PA\,dx$

Appendix A then gives a specifical calculated example: a reinforced concrete building of 952 metric tons, 75x75ft, 38 ft high, resisting force 4psi, subjected to a peak overpressure and dynamic pressure loading of 32psi decaying to zero in 0.32 second. Calculated peak deflection of middle of the building was 0.88 foot.

UNCLASSIFIED

Significant Reduction in Total Dose



Blast is not the only thing that is attenuated severely in a city: radiation including thermal and nuclear, is also attenuated. Although some scattered radiation gets through, it is usually degraded in energy and only comes from the small area of sky above you in a city street with tall buildings

UNCLASSIFIED

EXTRACTS

Table B–1. Severe/Moderate Blast Damage Radii for Surface Bursts (metesr)

Material classification		ALPHA 0.01	BRAVO 0.05	CHARLIE 0.10	DELTA 0.50	ECHO 1 KT
Field fortifcations	Mod	35	55	70	85	125
Earth covered surface shelters	Sev	35	60	65	80	100
Monumental-type multistory wall-bearing bldgs.	Mod	150	210	250	350	575
Multistory, wall-bearing bldgs (apt house type)	Sev	100	165	200	275	400
Multistory, reinforced bldgs (small windown area) Multistory, steel frame office bldgs.	Mod	65	100	130	200	350
Wood frame bldgs.	Sev	140	195	250	350	690

SOURCE: U.S. ARMY FIELD MANUAL "FM 5-26, EMPLOYMENT OF ATOMIC DEMOLITION MUNITIONS (ADM), AUGUST 1971".

PROTECTION (CASUALTY REDUCTION FACTOR) = AREA OF SEVERE DAMAGE FOR HIROSHIMA'S WOOD FRAME BUILDINGS / AREA OF SEVERE DAMAGE FOR EARTH COVERED SURFACE SHELTERS

$= 690^2 / 100^2 = 6.9^2 \sim 50$ FOR A 1 KILOTON SURFACE BURST.

SO MOVING TO EARTH COVERED SHELTERS REDUCES CASUALTIES TO 2%, AND THEY ALSO PROVIDE RADIATION SHIELDING. IN ADDITION, THE "FIRESTORM" AND ITS "SOOT NUCLEAR WINTER" FANTASY, WERE DEBUNKED BY GEORGE R. STANBURY, WHO PLANNED THE GERMAN FIRESTORMS; YOU NEEDED 50% IGNITION OF MEDIEVAL WOODEN HOUSES IN HAMBURG TO START A FIRESTORM, WHEREAS THE SIMPLE FIREBALL SHADOWING OF HIGH-RISE MODERN CITY SKYLINES REDUCES THIS TO 5% OR LESS, PREVENTING FIRESTORMS AND CLIMATIC EFFECTS. THIS IS SUPPRESSED BY THE NUCLEAR EXAGGERATIONS BIAS OF JOURNALISTS.

CHANGE 1

Field Manual No 101-31-1

NUCLEAR WEAPONS EMPLOYMENT DOCTRINE AND PROCEDURES

Radius of vulnerability (emergency risk criterion: 5% combat ineffectiveness)

Figure 54. Radii of Vulnerability.

CATEGORY — PERSONNEL (LL) IN— (Based on Governing Effect)

Radii listed are distances at which a 5 percent incidence of effect occurs. HOB used is $60W^{1/3}$ meters.

(Distances are in meters)

Yield (KT)	Open	Open Foxholes	APCs	Tanks	Earth Shelter
0.1	700	600	600	500	300
1	1200	900	900	800	500
10	3200	1300	1300	1250	900
20	4000	1500	1450	1400	1000
100	8000	1900	1800	1800	1400
200	12000	2000	1900	1900	1500
300	14000	2100	1950	1950	1600

Protective factor = ratio of area of effect in the open, to area of effect for shelter

Example: for 300 kt, the protective factor of open foxholes is equal to $(14{,}000)^2/(2{,}100)^2 = 44$.

Open	Open Foxholes	APCs	Tanks	Earth Shelter	Yield (KT)
1	1.36	1.36	1.96	5.44	0.1
1	1.78	1.78	2.25	5.76	1
1	6.06	6.06	6.55	12.6	10
1	7.11	7.61	8.16	16.0	20
1	17.7	19.8	19.8	32.7	100
1	36.0	39.9	39.9	64.0	200
1	44.4	51.5	51.5	76.6	300

Calculation of the injury-averting protective factors by simple open foxholes and earth shelters, as a function of weapon yield. Most countermeasures are relatively ineffective against tactical nuclear wapons (due to the predominating neutron radiation effect at 0.1 kt yield), but are extremely effective against strategic nuclear weapons with yields of 100, 200 and 300 kt (protective factors of 44 to 77).

The definition of protective factor used here is the factor by which casualties numbers are reduced.

https://www.cia.gov/readingroom/docs/DOC_0001260463.pdf

Secret

TIER 10/6

Intelligence Memorandum

Office of Transnational Issues — *30 August 2000*

(b) (1)
(b) (3)

Evidence of Russian Development of New Subkiloton Nuclear Warheads

CIA OTI IM 2000-011 X

public statements by Russian scientists and officials since 1993 indicate that the last nuclear warhead designed during the Soviet era was a device tailored for enhanced output of high-energy X-rays with a total yield of only 300 tons.

Judging from Russian writings since 1995 and Moscow's evolving nuclear doctrine, new roles are emerging for very-low-yield nuclear weapons—including weapons with tailored radiation output—and there are powerful advocates for development of such weapons in the country's military and weapons community. The Moscow press claimed that a draft presidential edict from Yel'tsin called for "development of new-generation nuclear weapons."

APPROVED FOR RELEASE
DATE: OCT 2005

- Recent statements on Russia's evolving nuclear weapons doctrine lower the threshold for first use of nuclear weapons and blur the boundary between nuclear and conventional warfare. Very-low-yield nuclear weapons reportedly could be used to head off a major conflict and avoid a full-scale nuclear war.

In the post-Soviet era, the need for subkiloton nuclear weapons with minimal long-term contamination has been argued in the media by senior Ministry of Atomic Energy (Minatom) officials, nuclear weapons scientists, and military academics since the mid-1990s. Advocates often claim to know that the United States is developing the next generation of nuclear weapons and argue that Russia must not lag behind. Somewhat inconsistently, they also cite clean, very-low-yield weapons as an "asymmetric response" to US superiority in conventional weapons. According to Sergei Rogachev, Deputy Director of the Arzamas-16 nuclear weapons design laboratory: "Russia views the tactical use of nuclear weapons as a viable alternative to advanced conventional weapons."

- Senior Russian military officers have advocated the use of highly-accurate, super-low-yield nuclear weapons in Russian military journals such as *Military Thought* and *Armeyskiy Sbornik*. Deputy Commander in Chief of the Strategic Rocket Forces Muravyev stated that to have an effective impact across the entire spectrum of targets, strategic missile systems should be capable of conducting surgical strikes in a wide spectrum of ranges with minimal ecological consequences, which could be achieved with low-yield nuclear weapons.

Soviet Era Development of Tailored - Output Nuclear Devices

Russian development of nuclear devices tailored to enhance certain types of radiation output began during the Soviet period when "clean" nuclear devices—that is with reduced contamination from fission products—were needed for peaceful nuclear explosions (PNE's), according to statements by the developers. Clean PNE devices were in effect the first enhanced-radiation devices produced in Russia and likely precursors of tailored-output devices developed later for both effects testing and weapons development, which involved the same scientists (see appendix B for detailed discussion).

Enhanced-radiation weapons are designed to increase the effective range of gamma, neutron, X-ray, or electromagnetic pulse effects beyond the range of the airblast and fireball effects. Clean PNE devices are designed to minimize contamination from fission products by maximizing the fraction of the total yield produced by fusion. The two objectives are achieved by similar design approaches.

- Former Atomic Energy Minister Mikhaylov, other nuclear scientists, military officers, and national security commentators have described these new weapons as blurring the boundaries between conventional and nuclear war. In a 1996 treatise, Mikhaylov advocated developing a new generation of nuclear battlefield arms with relatively low yields that would change the perception of nuclear arms as weapons of mass destruction. In 1999, he claimed that these new-generation nuclear charges would sharply lower the psychological threshold of nuclear weapons use and would increase the likelihood of a nuclear strike in a local conflict, according to an independent Russian military newspaper.

- ***The development of low-yield warheads that could be used on high-precision weapon systems would be consistent with Russia's increasing reliance on nuclear weapons to deter conventional as well as nuclear attacks, especially given widespread perceptions of a heightened threat from NATO and the reduced capabilities of Russian conventional forces.*** Russia has no prospect of restoring its conventional military capabilities in the foreseeable future, nor of matching the West in the procurement and deployment of advanced weapon systems that can be brought to bear at the nonnuclear level.

The possible diverse applications for subkiloton nuclear weapons devices range from tactical battlefield weapons to antisatellite weapons. Media reports have noted that current modernization plans will affect Russia's entire stockpile, from tactical to strategic weapons. According to the December 1999 issue of the Army Journal *Armeyskiy Sbornik:*

> "For an effective impact across the entire spectrum of targets, strategic missile systems should be capable of conducting 'surgical' strikes over a wide spectrum of ranges in the shortest period of time with minimal ecological consequences. This is achieved by using highly accurate, super-low-yield nuclear weapons, as well as conventional ones, and requires the highest accuracy."

The range of applications will ultimately be determined by Russia's evolving nuclear doctrine, and could include artillery, air-to-air missiles, ABM weapons, anti-satellite weapons, or multiple rocket launchers against tanks or massed troops.

NOTE: the last Russian nuclear weapon test in Ukraine was on 16 September 1979, "coincidentally" the same 0.3 kiloton (300 tons of TNT) yield as the new Russian battlefield tactical nuclear warheads! Because of the atmospheric nuclear test ban at that time, it was set off 900m below ground in the Ukrainian coal mine at Yunkom in Donetsk as a "safety precaution" allegedly to release methane gas! This mine "resumed normal operations" the next day.

Russia's Evolving Nuclear Doctrine

Since the dissolution of the USSR in 1991, Moscow's military doctrine has undergone a major shift with respect to the possible use of nuclear weapons. The deterioration of Russia's conventional military capabilities led to the adoption of a broadened concept of nuclear deterrence as early as the fall of 1992. Russia's nuclear arsenal was invoked to deter any large-scale conventional aggression in addition to nuclear attacks.

This concept in turn necessitated a rethinking of the old Soviet pledge—initially endorsed by President Yel'tsin—that Moscow would never be the first to use nuclear weapons. A November 1993 statement of *Basic Provisions of the Military Doctrine of the Russian Federation* clearly departed from the decade-old pledge never to be the first to use nuclear weapons and adopted a broadened concept of nuclear deterrence covering large-scale, nonnuclear threats to Russia. As a warning to potential adversaries, Moscow indicated it might use nuclear weapons first if an aggressor takes actions to destroy or disrupt operation of Russia's strategic nuclear forces, missile attack warning system, or nuclear and chemical industries.

WASHINGTON SCENE...*from the AIAA Washington*

ASTRONAUTICS & AERONAUTICS
January 1981

● CIA Deputy Director John McMahon, in testimony before a House Intelligence Subcommittee, estimated that the Soviet Union had spent $200 million on propaganda and covert campaigns against NATO deployment of enhanced-radiation (neutron-bomb) weapons and the modernization of theater nuclear weapons.

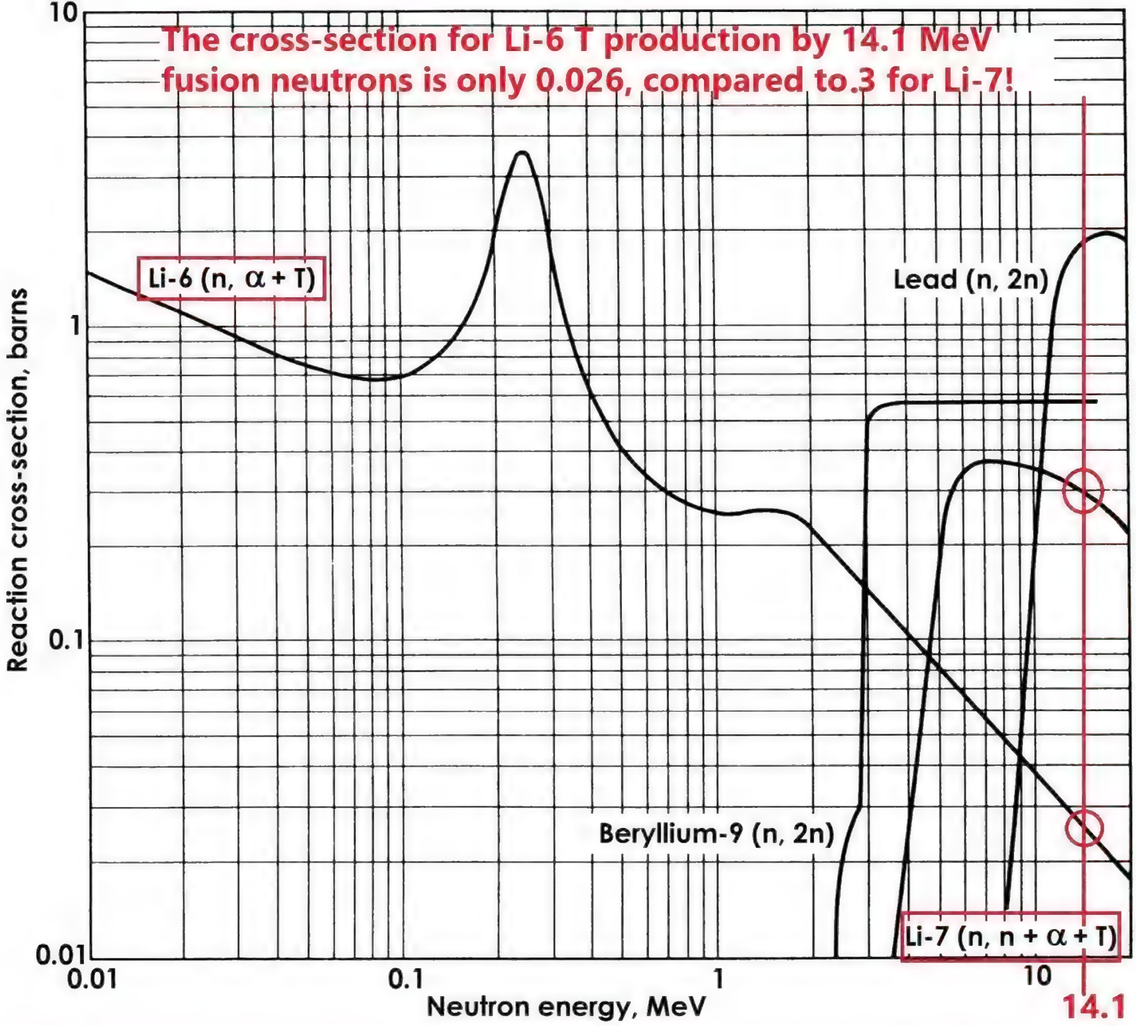
Enhanced radiation weapons (ERW) increase radiation while greatly reducing blast (tenfold) and heat damage to surrounding areas. Made for use in short-range, tactical nuclear weapons such as the Lance missile and 8-in. howitzer, they would probably be used against large concentrations of Warsaw Pact tanks, a major threat to NATO.

The campaign against the neutron bomb began in the summer of 1977 and was manifested in a series of coordinated diplomatic moves, overt propaganda, and covert political action, said McMahon. It began in the Soviet and East European press and spread to communist international front groups all over the world. "The purpose of this front-group activity was to maintain the campaign's momentum and to draw noncommunists into the campaign, particularly in Western Europe. What had begun as a Soviet effort now appeared to many as a general public reaction to the alleged horrors of the neutron bomb," said McMahon.

By far the most important comments, said McMahon, appeared in the noncommunist press in the political center

While it is difficult to assess the full impact of the anti-neutron-bomb campaign, the Carter Administration in April of 1978 deferred production of the enhanced-radiation element of the warheads indefinitely while proceeding with modifications to the warheads themselves to make them compatible with ER components. In commenting on the results of the Soviet bloc campaign, the CIA testimony quoted the chief of the International Department of the Hungarian Communist Party, Janos Berecz, as saying, "The political campaign against the neutron bomb was one of the most significant and most successful since World War II." McMahon also noted that "the Soviet Ambassador to the Hague (Netherlands) at that time was subsequently decorated by the CPSU (Communist Party of the Soviet Union) in recognition of the success of the Dutch Communist Party, under his direction, in organizing the high point of the anti-neutron bomb campaign."

With the neutron bomb temporarily defused, testified McMahon, the Soviet Bloc turned its efforts against the U.S.-initiated move to modernize the theater nuclear forces (TNF) by deploying the highly accurate ground-launched cruise missile (GLCM) and the Pershing II missile. Scheduled for deployment in late 1983, they will, for the first time, place targets on Soviet soil within range of NATO ground-based missiles. The purpose of the modernization is to minimize the



Proved in the successful 9.96 megaton Ripple II secondary stage test (99.9% clean bomb, employing 10 kt boosted Kinglet primary) by John Nuckolls; Dominic Housatonic, on 30 October 1962.

The Ripple II nuclear test secret: why lithium-7 is actually better in boosted clean secondaries than lithium-6! For 14.1 Mev neutrons from T+D fusion, lithium-7 has a 0.3 barns cross-section, compared to just 0.026 for lithium-6! Plus, it gives ANOTHER neutron UNLIKE lithium-6.

Change in entropy,

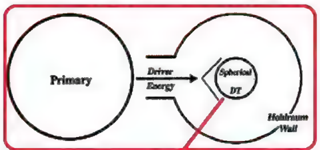
$$\Delta S = nC_v ln(T/T_o) + nRln(V/V_o)$$

Hence, for isentropic compression (no change in entropy):

$$\Delta S = 0$$

Therefore:

$$C_v ln(T/T_o) = -Rln(V/V_o)$$



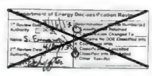
Ripple II (boosted Li6D in Be ablator)

~~SECRET/RESTRICTED DATA~~

Hydrodynamic and Nuclear Experiments (U)

November 2011

JSR-11-340



Pages 72-3 and Fig 26 on p73 show how "X-rays drive a plasma 'hammer' that quasi-isentropically compresses the target", the target "anvil" being beryllium-coated rippled-interface plutonium

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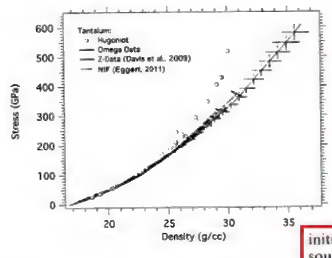


Figure 25: Measurements of the off-Hugoniot Ta EOS

John H. Nuckolls discovered isentropic compression theory for clean thermonuclear weapons from 1957-62 and he successfully tested 99.9% clean 10 megatons Housatonic on 30 October 1962, using 0.3kev x-rays (to avoid radiation wall losses) on a non-pusher (pure ablator)

Ramp = isentropic

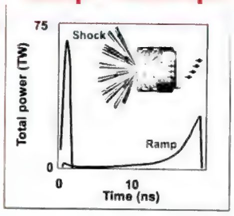
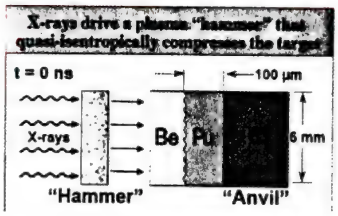


Figure 24: Left: the use of pulse shaping

Figure 26:



***Nature*, 15 September 1972**

initial shock speed in the imploding matter is comparable to sound speed (pressures of 10^5–10^6 atmospheres) and subsequently so that the compression is near-isentropic;

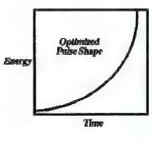
Optimum x-ray pulse shape needed isentropic Ripple II:

$$\dot{E} = \dot{E}_0 \tau^{-s}$$

where $\tau = 1 - t/t'$, t is time, t' (which is $> t$) is the transit time to the centre of the sphere of the initial shock (generated by application of $\dot{E}_0$), $s = \frac{3\gamma}{\gamma+1} = 15/8$ for dense hydrogen with degenerate electrons ($\gamma = 5/3$). **(Nuckolls in *Nature*, v239, p139, 1972)**

initially shock compress Pu and then drive it isentropically in a way similar to the environment experienced by a Pu particle in an imploding primary. The concept is shown graphically in Figure 24. Of course, the actual design of the appropriate pulse

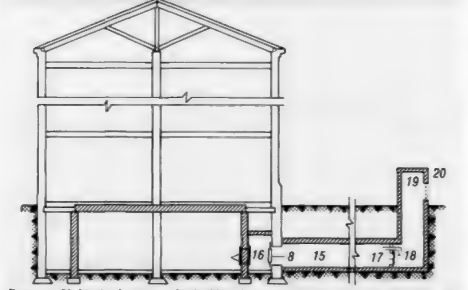
encouraging. In Figure 25 we show results from explorations of the Ta EOS on several platforms. The results shown correspond to isentropic compression As can be seen the new NIF data are in good agreement with previous data from the Omega laser and are also in agreement with data obtained on the Z pulsed power platform at SNL. The results are the highest pressure off-Hugoniot data achieved to date.



***Pulse shape is* $(1 - t)^{-1.875}$**

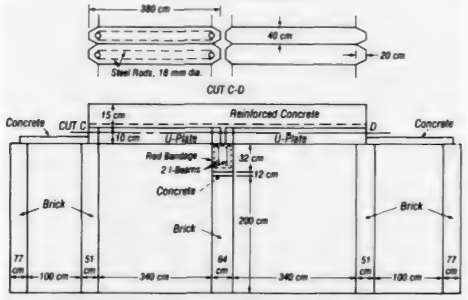
Which is produced using plastic foam baffles to control the x-ray transit from the primary stage

~~SECRET/RESTRICTED DATA~~



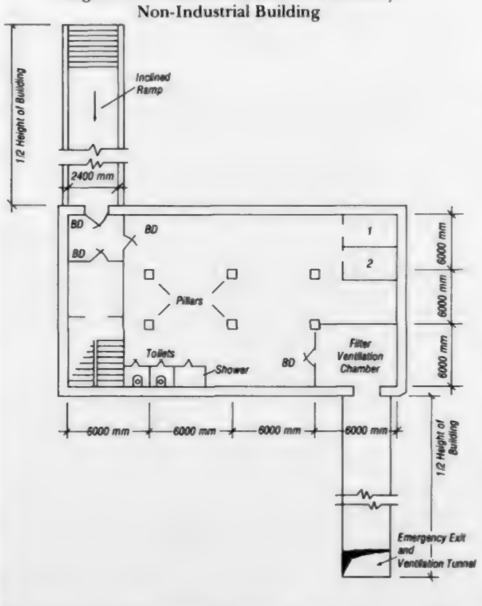
Basement Shelter in the center of a building basement: **(1)** *compartments;* **(2)** *exits;* **(3)** *and* **(4)** *protective airtight doors;* **(5)** *louvered wooden door;* **(6)** *vestibule;* **(7)** *protective airtight shutters;* **(8)** *shutter with dust filter;* **(9)** *filter-ventilation chamber;* **(10)** *lavatories;* **(11)** *exhaust duct;* **(12)** *sealing safety valve;* **(13)** *basic air intake duct;* **(14)** *pressurized pipes;* **(15)** *emergency exit;* **(16)** *adjoining chamber;* **(17)** *airtight safety shutter in emergency exit;* **(18)** *floating cutoff valve;* **(19)** *vent cap of the emergency exit;* **(20)** *wooden louver grating*

Basement Shelters



Cross Section of a Basement Shelter Using Prefabricated U-Plates and Cast Reinforced Concrete Slab Roof

Diagram of a Basement Shelter in a Six-Story, Non-Industrial Building

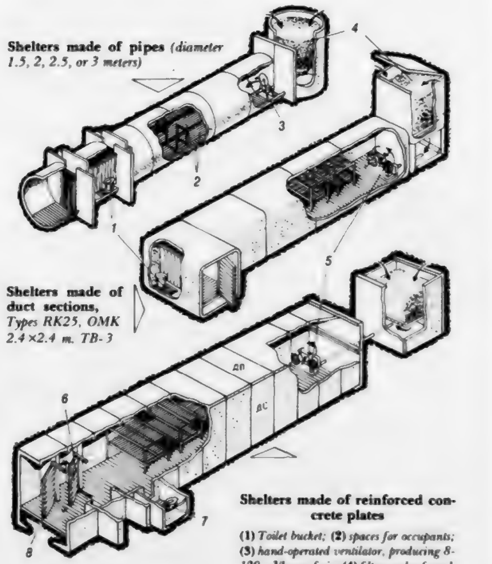


(1) storage for reserve of drinking water; **(2)** *storage for a five-day supply of food;* **(BD)** *hermetically-sealing metal doors, height 1.8 m*

Pillars of reinforced concrete 0.65 m × 0.65 m × 3m

REMARKS: All dimensions are in millimeters

Expedient Shelters



Shelters made of reinforced concrete plates

(1) *Toilet bucket;* **(2)** *spaces for occupants;* **(3)** *hand-operated ventilator, producing 8-120 m³/hour of air;* **(4)** *filter made of sand, slag, with capacity of 150-220 m³/hour of air;* **(5)** *bicycle;* **(6)** *hermetic-sealing doors with air valve;* **(7)** *toilet;* **(8)** *protective door with hermetic seal*

Dr Leon Goure, Shelters in Soviet War Survival Strategy, ADA053250, 1978.

TK Jones became President Reagan's civil defense expert, debunking propaganda:

1. Ostensible Crisis
2. Political, Economic, and Diplomatic Gestures
3. Solemn and Formal Declarations
4. Hardening of Positions—Confrontation of Wills
5. Show of Force
6. Significant Mobilization
7. "Legal" Harassment—Retortions
8. Harassing Acts of Violence
9. Dramatic Military Confrontations
10. Provocative Breaking Off of Diplomatic Relations
11. Super-Ready Status
12. Large Conventional War (or Actions)
13. Large Compound Escalation
14. Declaration of Limited Conventional War
15. Barely Nuclear War
16. Nuclear "Ultimatums"
17. Limited Evacuation (Approximately 20 per cent)
18. Spectacular Show or Demonstration of Force
19. "Justifiable" Counterforce Attacks
20. "Peaceful" World-Wide Embargo or Blockade
21. Local Nuclear War—Exemplary
22. Declaration of Limited Nuclear War
23. Local Nuclear War—Military
24. Unusual, Provocative, and Significant Countermeasures
25. Evacuation (Approximately 70 per cent)
26. Demonstration Attack on Zone of Interior
27. Exemplary Attack on Military
28. Exemplary Attacks Against Property
29. Exemplary Attacks on Population
30. Complete Evacuation (Approximately 95 per cent)
31. Reciprocal Reprisals
32. Formal Declaration of "General" War
33. Slow-Motion Counter-"Property" War
34. Slow-Motion Counterforce War
35. Constrained Force-Reduction Salvo
36. Constrained Disarming Attack
37. Counterforce-with-Avoidance Attack
38. Unmodified Counterforce Attack
39. Slow-Motion Countercity War
40. Countervalue Salvo
41. Augmented Disarming Attack
42. Civilian Devastation Attack
43. Some Other Kinds of Controlled General War
44. Spasm or Insensate War

Herman Kahn's Escalation Ladder of Steps the left will try to engineer to start WWIII.

BOEING AEROSPACE COMPANY

P O Box 3999
Seattle, Washington 98124

A Division of The Boeing Company

January 22, 1979

The Honorable William Proxmire
Chairman, Senate Banking Committee
United States Senate
Washington, D.C.

Dear Senator Proxmire:

Your request in recent hearings for an explanation of the discrepancy between our estimates and ACDA's estimates of Soviet losses in a nuclear war is clearly important and warrants a clear and candid answer. Unfortunately, Mr. Spurgeon Keeny, the Deputy Director of ACDA, chose to incorrectly represent our work. I appreciate the opportunity to set the record straight and to point out what we have determined to be the factors contributing significantly to the differences between the two estimates.

Population Protection

In his attempt to discredit our work, Mr. Keeny incorrectly inferred that this work was based on mere "assumptions" and "simple ratios." In fact, our approach was to analytically duplicate the provisions of the Soviet Union's civil defense plans and preparations. This effort was supported by extensive research into Soviet literature, use of rigorous system engineering functional analysis techniques, and a program of testing to establish the effectiveness of Soviet shelters and industrial protection methods. Moreover, the impact of uncertainties and possible imperfections in Soviet execution of their plans were examined parametrically.

Mr. Keeny's statement that we "assumed there would be no casualties from fallout" is false. The record of hearings before the Joint Committee on Defense Production (November 17, 1976) clearly shows that the data presented counted as fatalities all persons receiving a radiation dose of 200 rads or more. Moreover, our more recent studies of which ACDA is aware have treated this value parametrically.

By protecting their people against fallout, the Soviets can substantially limit their population fatalities. Figure 1 shows that even very rudimentary protection, such as basements or expedient shelters, is sufficient to minimize fatalities. In the ACDA analysis, the majority of the evacuees were assumed to have a protection factor of 10 or less, which results in enormously high fatalities compared to what the Soviets could achieve if they carry out even the most modest of the measures outlined in their plans and literature.

Assumption Variables Versus U.S.S.R. Civil Defense Effectiveness

Degree of Fallout Protection for Evacuees and Rural Population

BOEING

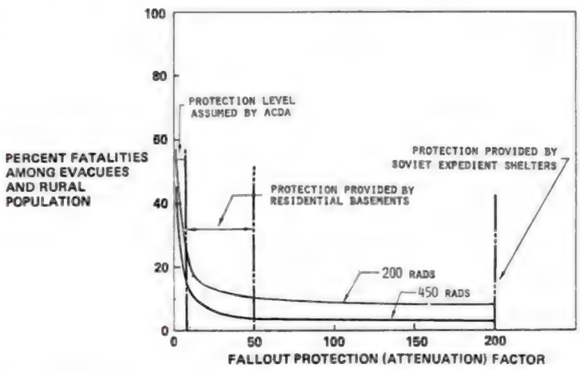


FIGURE 1

Mr. Keeny has incorrectly characterized our treatment of blast protection. In their cities, the Soviets are building industrial shelters and apartment basement shelters with a blast resistance of at least 150 psi and 60 psi, respectively. These ratings were calculated for the Defense Nuclear Agency based on knowledge of construction details such as beam dimensions, concrete quality, and structural reinforcement size and placement. The Soviet designs for expedient shelters have been built and exten-

Assumption Variables Versus U.S.S.R. Civil Defense Effectiveness

Distance Evacuated

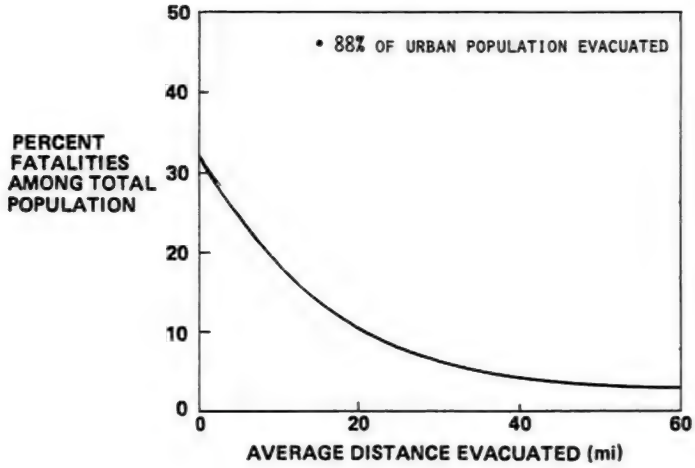


FIGURE 2

Assumption Variables Versus U.S.S.R. Civil Defense Effectiveness

Blast Protection Provided Evacuees and Rural Population

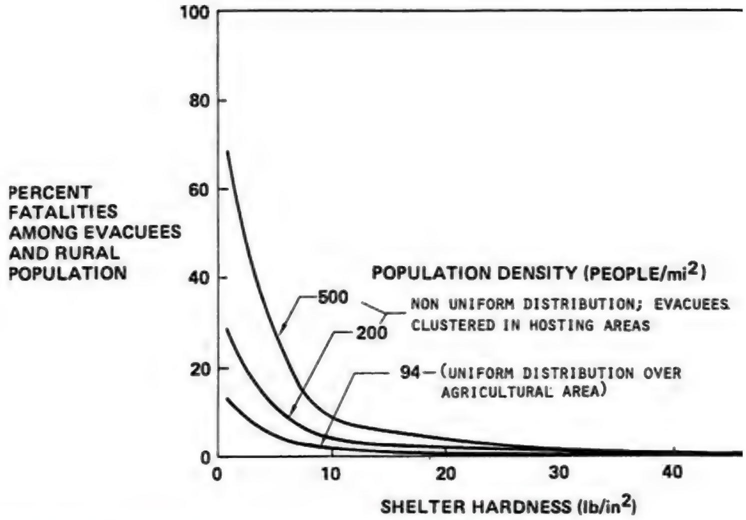


FIGURE 3

As to the reasons why our results differ from those produced by ACDA: ACDA assumed that 30 percent of the Soviet urban population would not be evacuated but that the good quality shelters would accommodate only 10 percent. Thus, 20 percent of the Soviet urban population was assumed unevacuated and inadequately protected, which of course subjects them to massive losses. The Soviet plans, which we endeavored to represent in our analysis, indicates that urban residents not sheltered will be evacuated.

A second difference centers around the way in which the Soviets choose to distribute and provide blast protection for their evacuees. The ACDA analysis assumed that the Soviets would cluster their evacuees in hosting areas, which we estimate could result in some concentrations as high as 500 persons per square mile. The evacuees were assumed to have no blast protection, so fatalities would occur at 3 to 7 psi according to the source used by ACDA. Figure 3 shows that a distribution of 500 persons per square mile and 3 psi fatal blast level results in a fatality level almost 100 times greater than a uniform distribution and blast protection to 15 psi (the minimum provided by Soviet expedient shelters). It is important to remember that it is the Soviet Union and not the United States that controls such factors as evacuation, distribution, and sheltering of the Soviet citizens.

The ACDA study of industrial protection, which I have reviewed, is not a competent work. The hardness levels known to be achievable on industrial components are seriously understated while the difficulty of achieving these levels is overstated. The resiliency of industry in recovering from damage is disregarded. The report's fixation on the capability of one-megaton weapons to damage industry is misleading since the U.S. would be able to deliver few of these weapons against Soviet targets. Moreover, the ACDA study fails to assess the impact of protection on the survival and recovery of the Soviet industrial base as a whole.

T.K. Jones

T. K. Jones

BOEING

TK JONES EXPOSED THE EVIDENCE DEBUNKING FAKE US ACDA/FEMA ANTI-CIVIL DEFENSE EFFECTS "DATA", USING EVIDENCE

USSBS Report 92, v2 Hiroshima buildings	MAE's in square miles	Radii of MAE's in feet
Multistory, earthquake-resistant	0. 03	500
Multistory, steel- and reinforced-concrete frame (including both earthquake- and non-earthquake-resistant construction)	. 05	700
1-story, light, steel-frame	3. 4	5, 500
Multistory, load-bearing, brick-wall	3. 6	5, 700
1-story, load-bearing, brick-wall	6. 0	7, 300
Wood-frame industrial-commercial (dimension-timber construction)	8. 5	8, 700
Wood-frame domestic buildings (wood-pole construction)	9. 5	9, 200
Residential construction	6. 0	7, 300

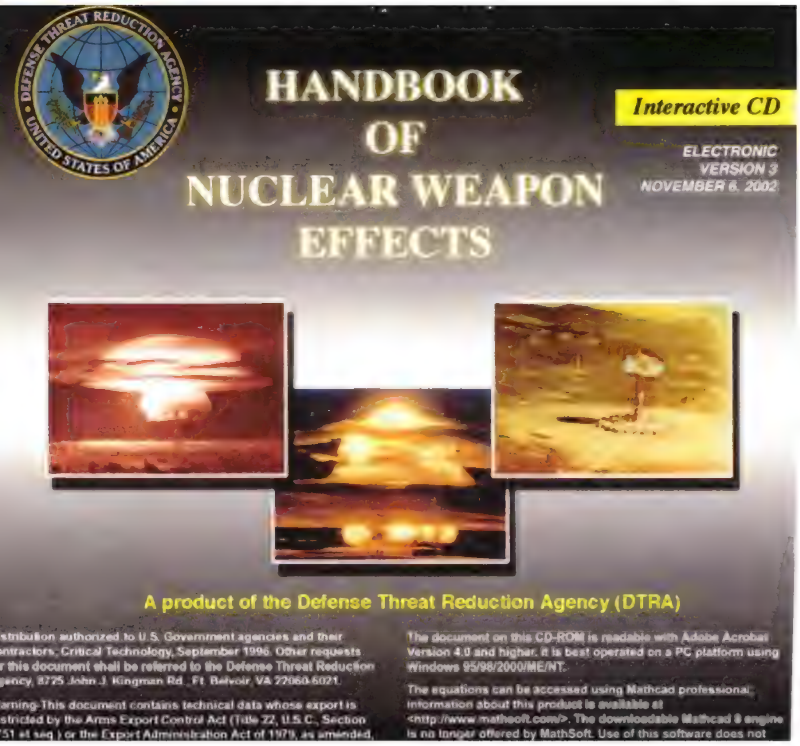


Table 15.17. Command Post and Personnel Shelter Vulnerability Levels for Peak Overpressure (psi).

PERCENT PROBABILITY OF DAMAGE	LEVEL OF DAMAGE		
	LIGHT	MODERATE	SEVERE
10	20	35	40
50	30	50	60
90	45	75	90

Table 15.18. Hardened Frame/Fabric Shelter Vulnerability Levels for Peak Overpressure (psi).

PERCENT PROBABILITY OF DAMAGE	LEVEL OF DAMAGE		
	LIGHT	MODERATE	SEVERE
10	20	35	40
50	30	50	60
90	45	75	90

EXPEDIENT FIELD SHELTERS: 4 FT EARTH COVER

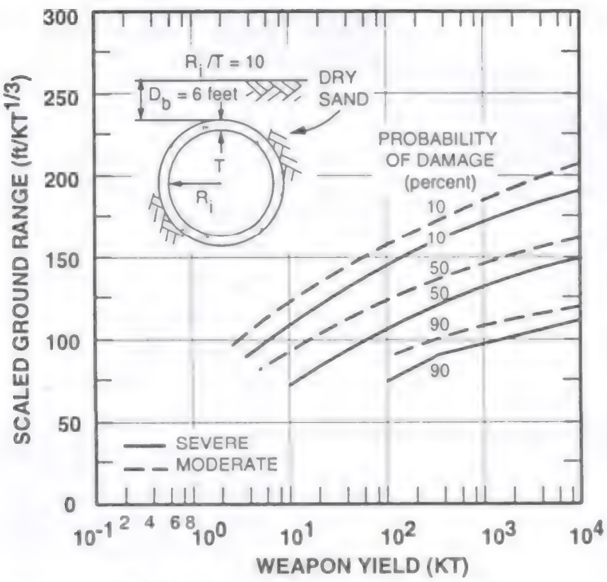


Figure 15.52. Vulnerability Curves for a Horizontal Cylinder, Aspect Ratio $R_i/T = 10$ (Structure Category 15.3.18) Buried in Dry Sand.

Russian buried KVS-U prefabricated buried corrugated steel shelter

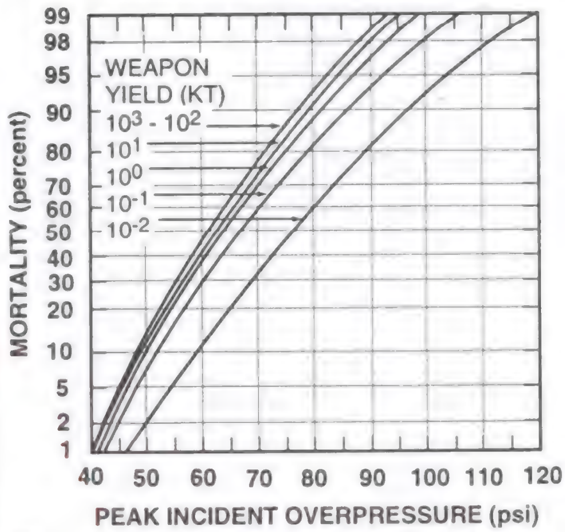


Figure 14.3. Mortality Due to Lung Injury; Long Axis of Body Parallel to Direction of Blast Wave.

July 1977 Commentary, pp 21-34: Commentary

Why the Soviet Union Thinks It Could Fight and Win a Nuclear War

Richard Pipes

3. The threat of a second strike, which underpins the mutual-deterrence doctrine, may prove ineffectual. The side that has suffered the destruction of the bulk of its nuclear forces in a surprise first strike may find that it has so little of a deterrent left and the enemy so much, that the cost of striking back in retaliation would be exposing its own cities to total destruction by the enemy's third strike. The result could be a paralysis of will, and capitulation instead of a second strike.

Experts refute CIA – Soviet civil defense

NEW YORK NEWS WORKD, 19 February 1978

By Vicki Tatz
NEWS WORLD WASHINGTON BUREAU

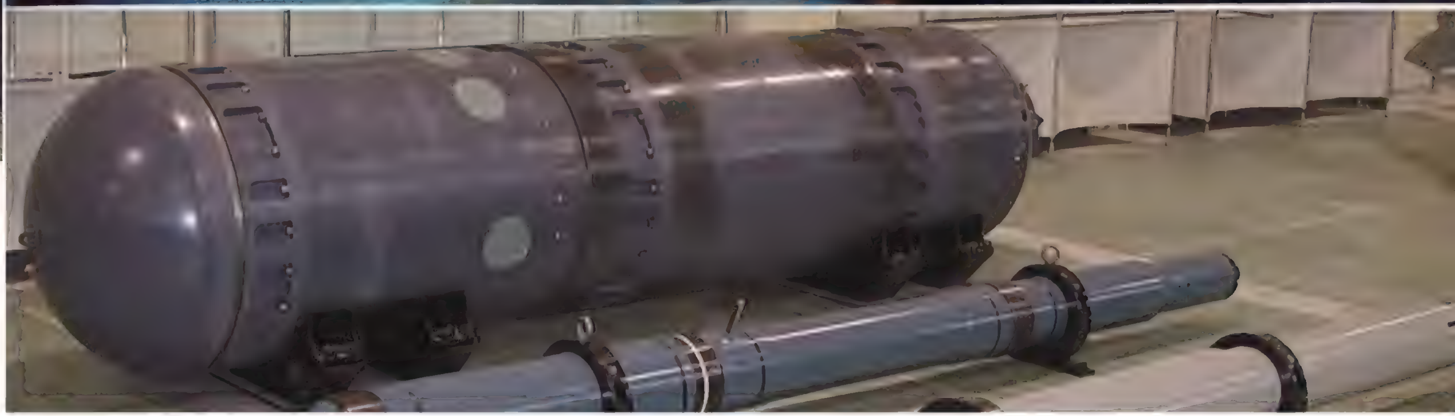
WASHINGTON—Two experts on Soviet civil defense capabilities disagreed sharply yesterday with statements released Friday indicating that the CIA does not place great significance on the massive Soviet preparations.

Dr. Eugenge Wigner, Nobel prize-winning physicist, and retired Gen. George Keegan, former chief of Air Force intelligence, both disagreed with Adm. Stansfield Turner, the director of the Central Intelligence Agency. In

"I don't know what the Soviets plan to initiate," Wigner said, "but the impression one gets is that they constantly claim that to destroy capitalist countries is all right, but to destroy socialism is a terrible crime."

Wigner referred to estimates made by himself and others that only between 2 percent and 5 percent of the Soviet Union's population would be vulnerable to a U.S. nuclear attack, while 45 percent of the U.S. population could be hit.

In another telephone interview Gen. Keegan said there was not the



Boris V. Litvinov showing Putin the world's smallest diameter (152.4mm) 2.5 kt artillery shell (above), and a 99.85% clean thermonuclear bomb (above right and right), 30 March 2000.

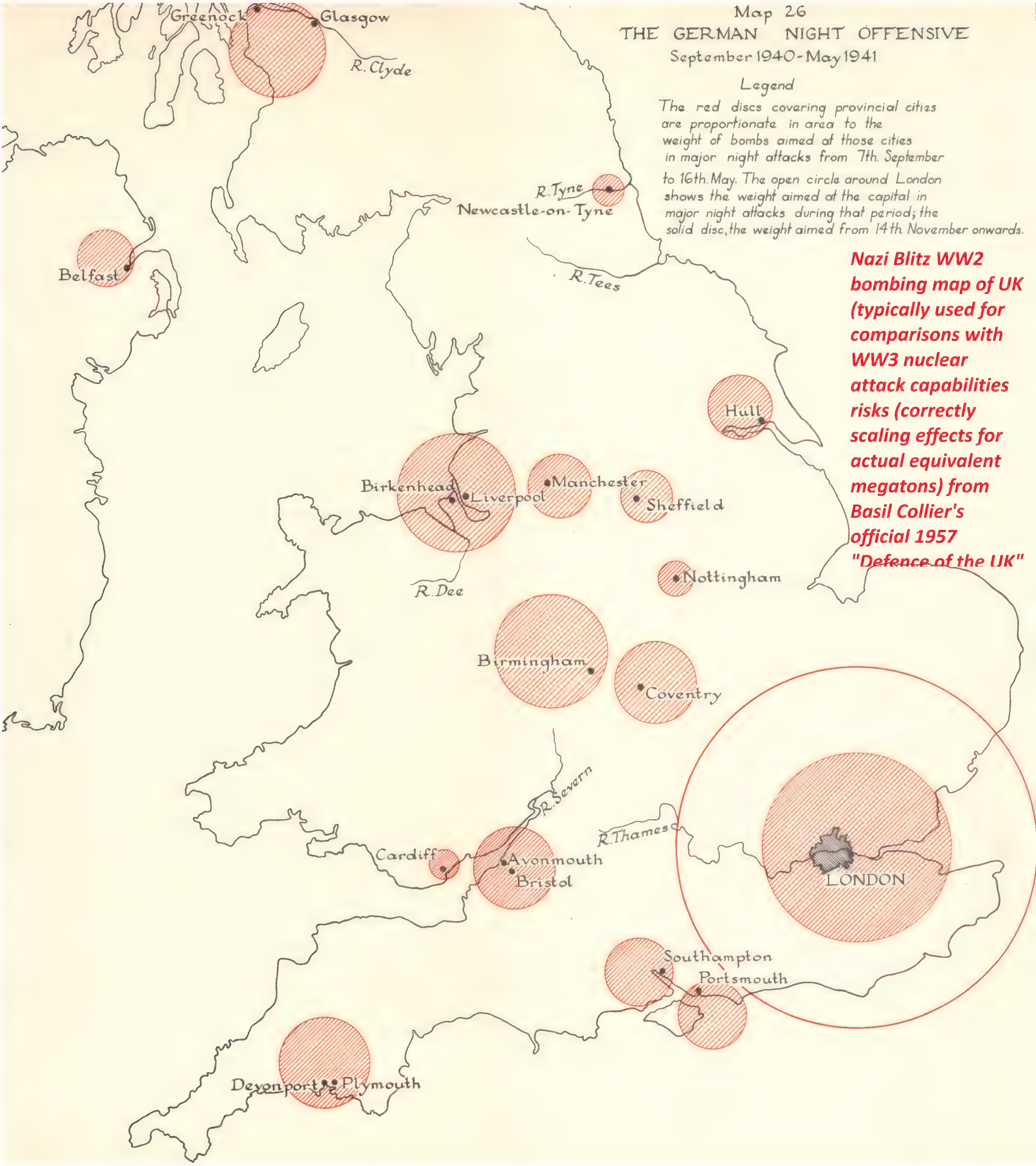
B.V. Litvinov, President Putin, P.I. Sumin at RFNC-VNIITF, 30 March 2000

E.N. Avrorin, B.V. Litvinov, President Putin, G.N. Rykovanov, E.O. Adamov, Yu.V. Solomon

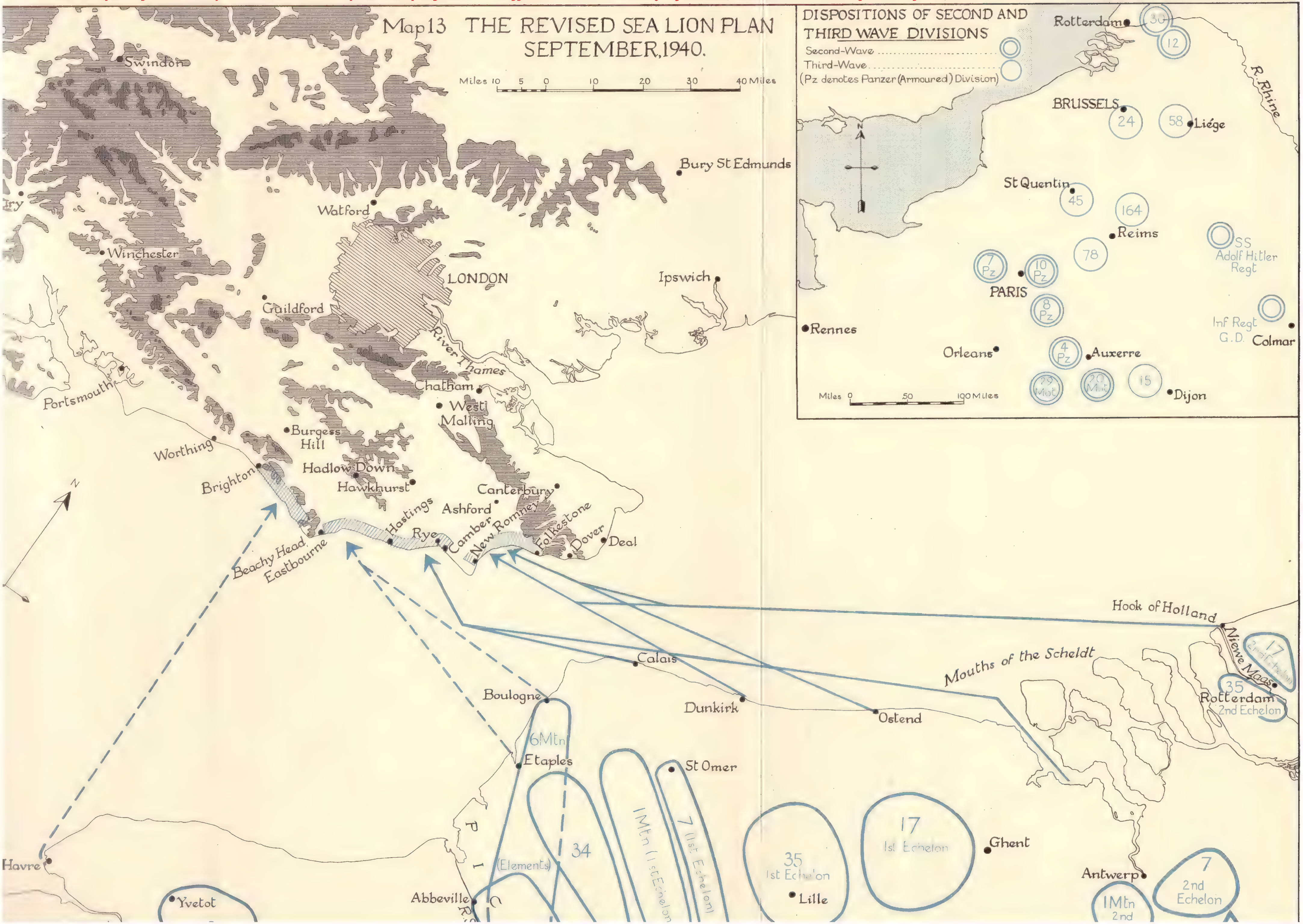
State visit of President Putin to RFNC-VNIITF, 30 March 2000

PRESIDENT PUTIN AWARDS NUCLEAR WARHEAD DESIGNER BORIS LITVINOV THE ORDER FOR MERIT TO THE FATHERLAND IN 2000.

For the 30 March 2000 state visit of President Putin to RFNC-VNIITF: B.K. Vodolaga, A.S. Shtanko, A.V. Oplanchuk, V.N. Zatsepin,M.E. Zheleznov, B.V. Litvinov, L.D. Ryabev, G.N. Rykovanov, N.P. Voloshin, E.N. Avrorin, THEM. Kamenskikh, V.Z. Kazachenkov, R.I. Wozniuk


Map 26
THE GERMAN NIGHT OFFENSIVE
September 1940-May 1941
Legend
The red discs covering provincial cities are proportionate in area to the weight of bombs aimed at those cities in major night attacks from 7th. September to 16th. May. The open circle around London shows the weight aimed at the capital in major night attacks during that period; the solid disc, the weight aimed from 14th. November onwards.
Nazi Blitz WW2 bombing map of UK (typically used for comparisons with WW3 nuclear attack capabilities risks (correctly scaling effects for actual equivalent megatons) from Basil Collier's official 1957 "Defence of the UK"
Greenock
Glasgow
R. Clyde
R. Tyne
Newcastle-on-Tyne
R. Tees
Belfast
Hull
Birkenhead
Liverpool
Manchester
Sheffield
R. Dee
Nottingham
Birmingham
Coventry
R. Severn
R. Thames
LONDON
Cardiff
Avonmouth
Bristol
Southampton
Portsmouth
Devonport
Plymouth

Nazi invasion plan for UK - Operation Sea Lion plan map - from the official British history of WW2, Basil Collier's Defence of UK, 1957



REFLECTIONS OF A NUCLEAR WEAPONEER

FRANK H. SHELTON

Frank H. Shelton

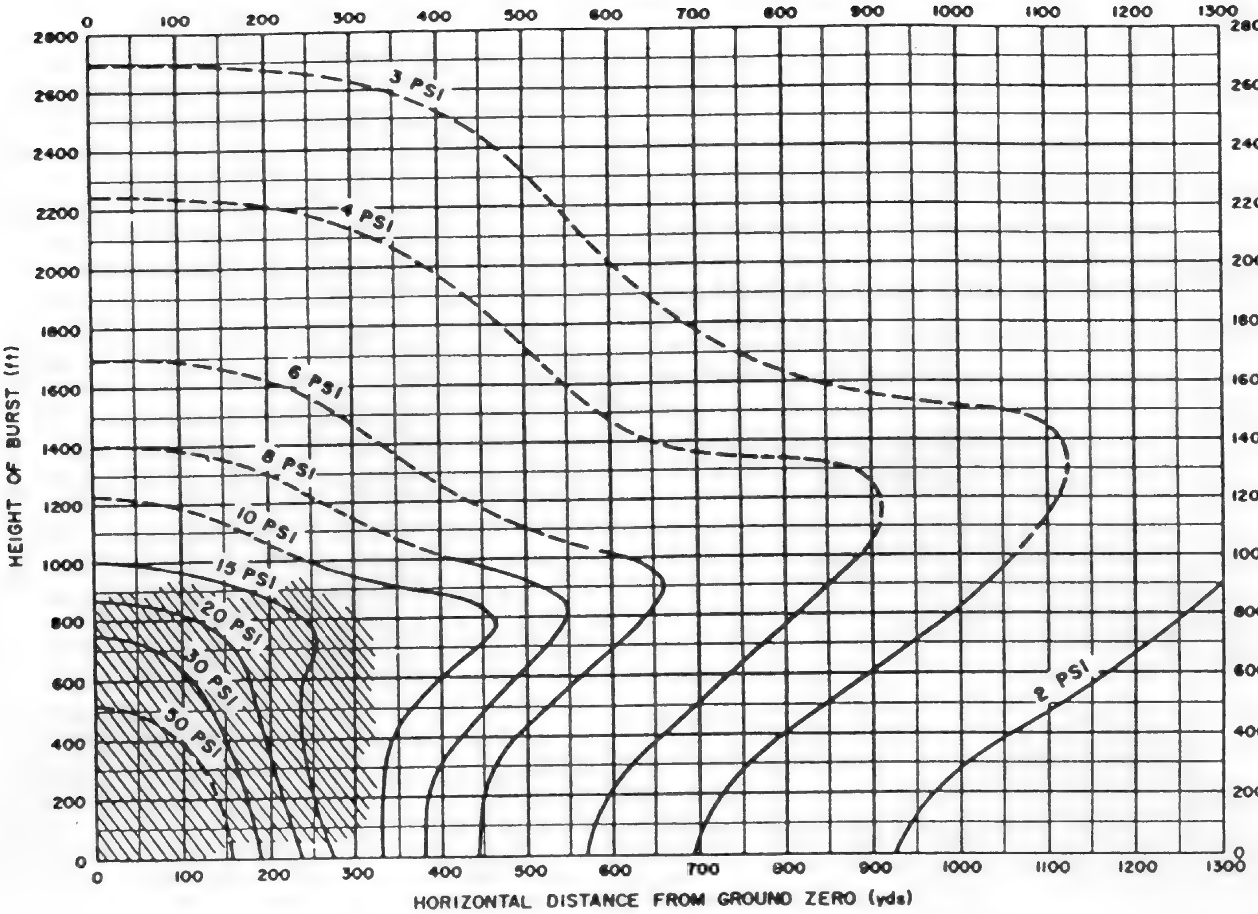


FIGURE 5-22. HEIGHT OF BURST CURVES (SCALED TO 1 KT AT SEA LEVEL)

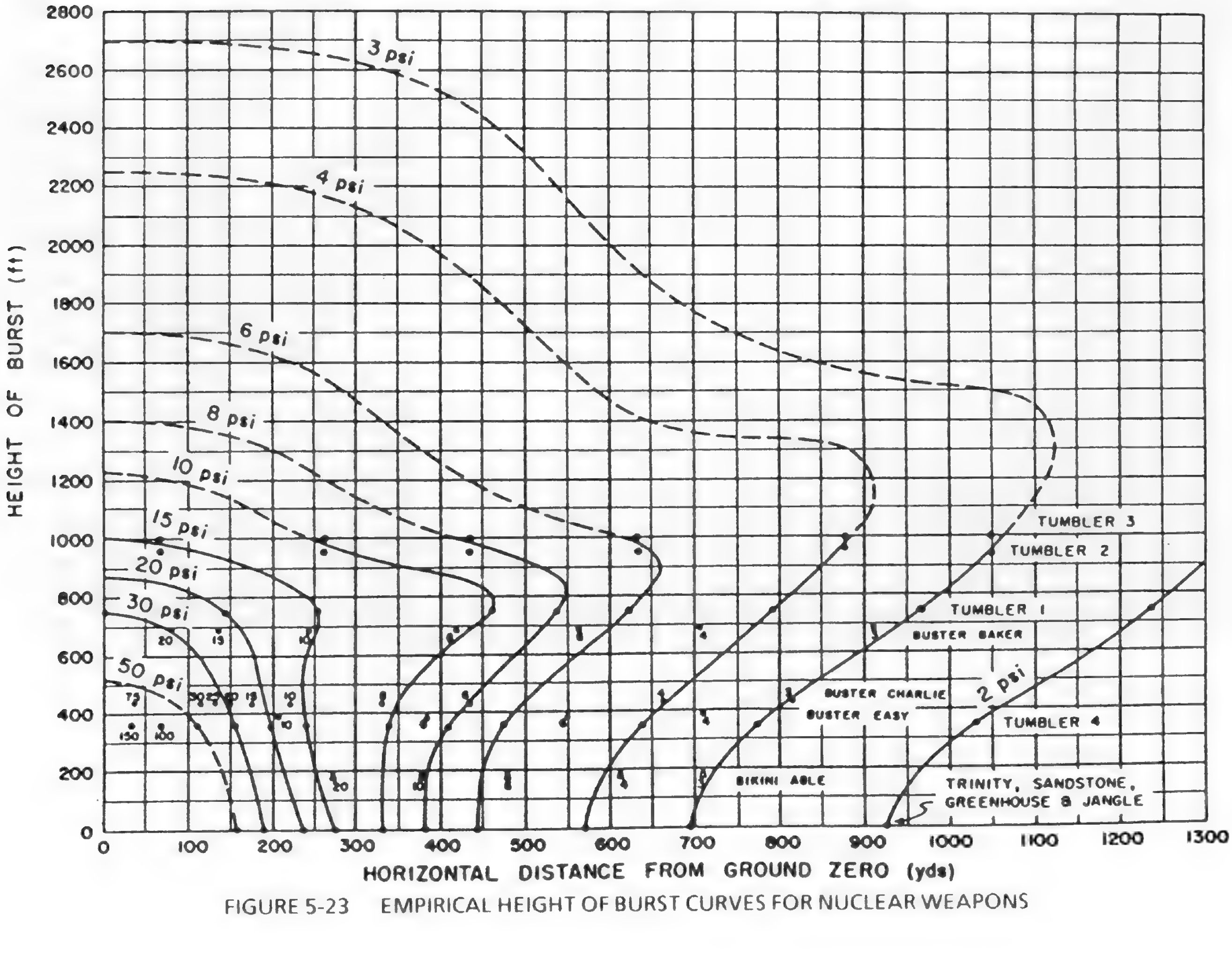


FIGURE 5-23 EMPIRICAL HEIGHT OF BURST CURVES FOR NUCLEAR WEAPONS

FIGURE 5-33. IVY MIKE D-1 (31 OCTOBER 1952) VIEWING NORTHWEST FROM STATION 200 TO SHOT CAB

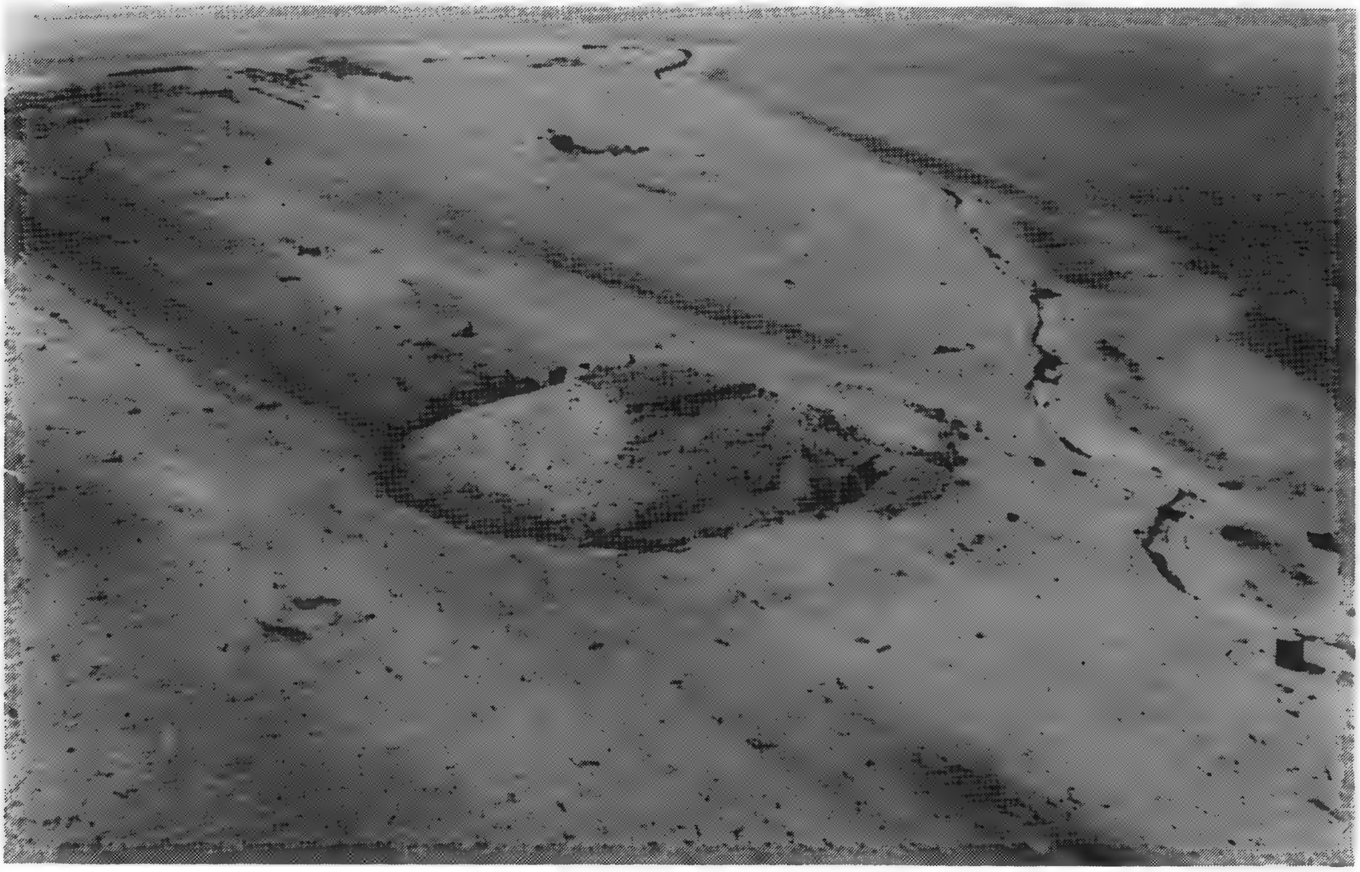
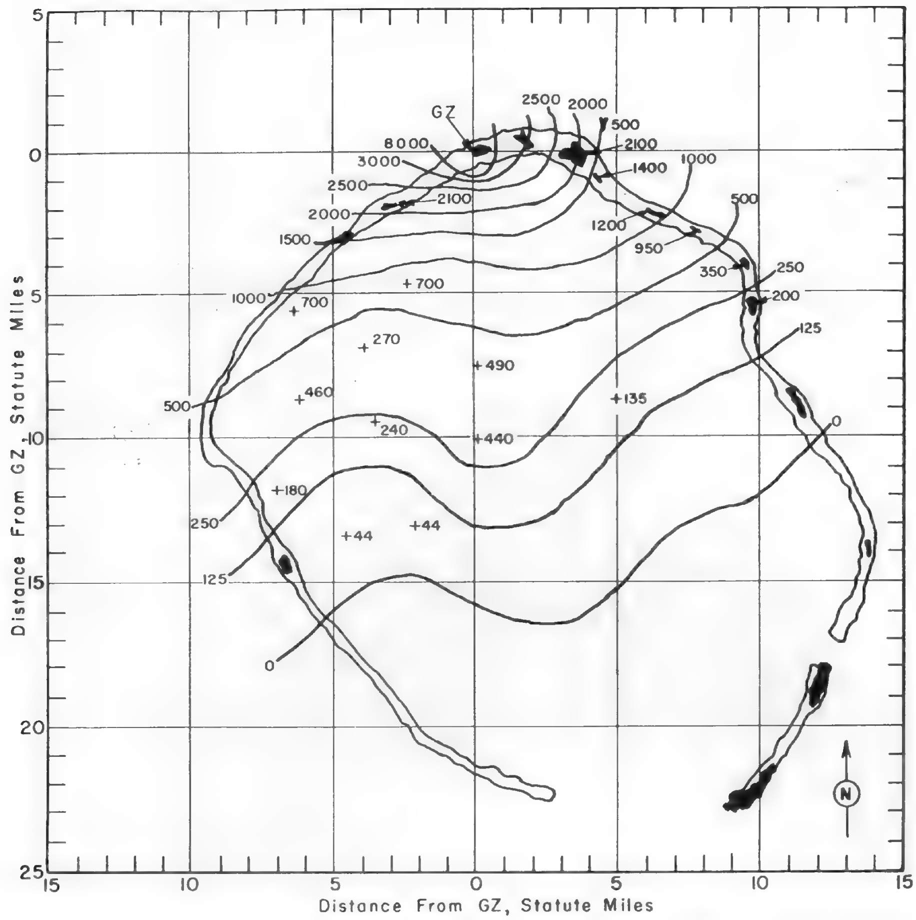


FIGURE 5-34. IVY MIKE POST-SHOT D + 2 (3 NOVEMBER 1952)
VIEWING NORTHWEST FROM STATION 200, SHOT PRESSURE WAS 330 PSI



IVY MIKE - ATOLL DOSE RATES IN R/HR AT H + 1 HR

RUCHI ISLAND WAS 2.3 KM WEST OF GROUND ZERO AT ABOUT 3000 R/HR AT ONE HOUR

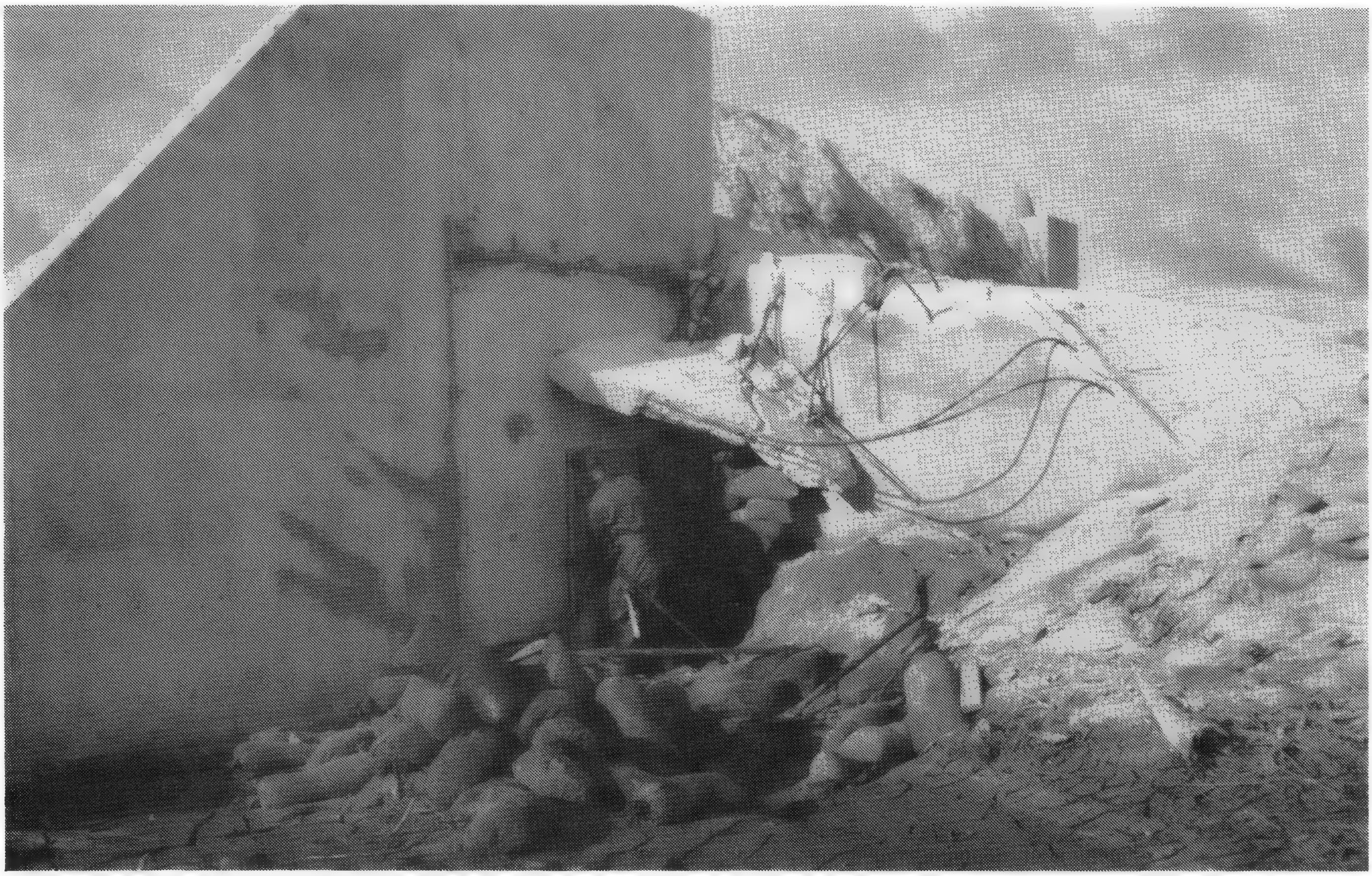


FIGURE 5-35. IVY MIKE POST-SHOT STATION 520 ON RUCHI ISLAND; JOHN MALIK ON REENTRY ON D + 4 (5 NOVEMBER 1952); DOSE RATE OF 3000 R/HR AT 1 HR HAD DECREASED TO ABOUT 12 R/HR. (30)

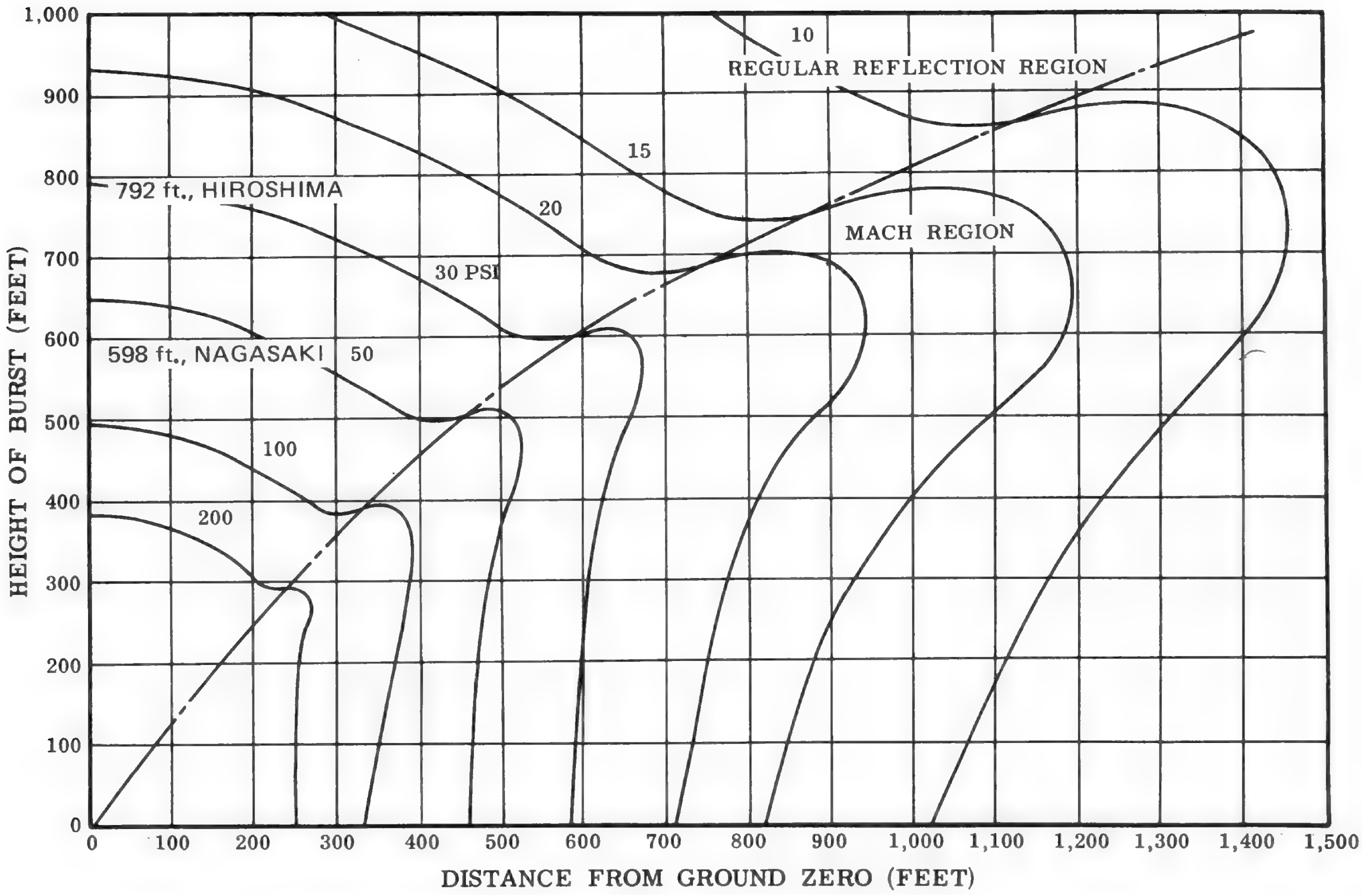


FIGURE 6-12. PEAK OVERPRESSURES ON THE GROUND FOR A 1-KILOTON BURST (HIGH PRESSURE RANGE)

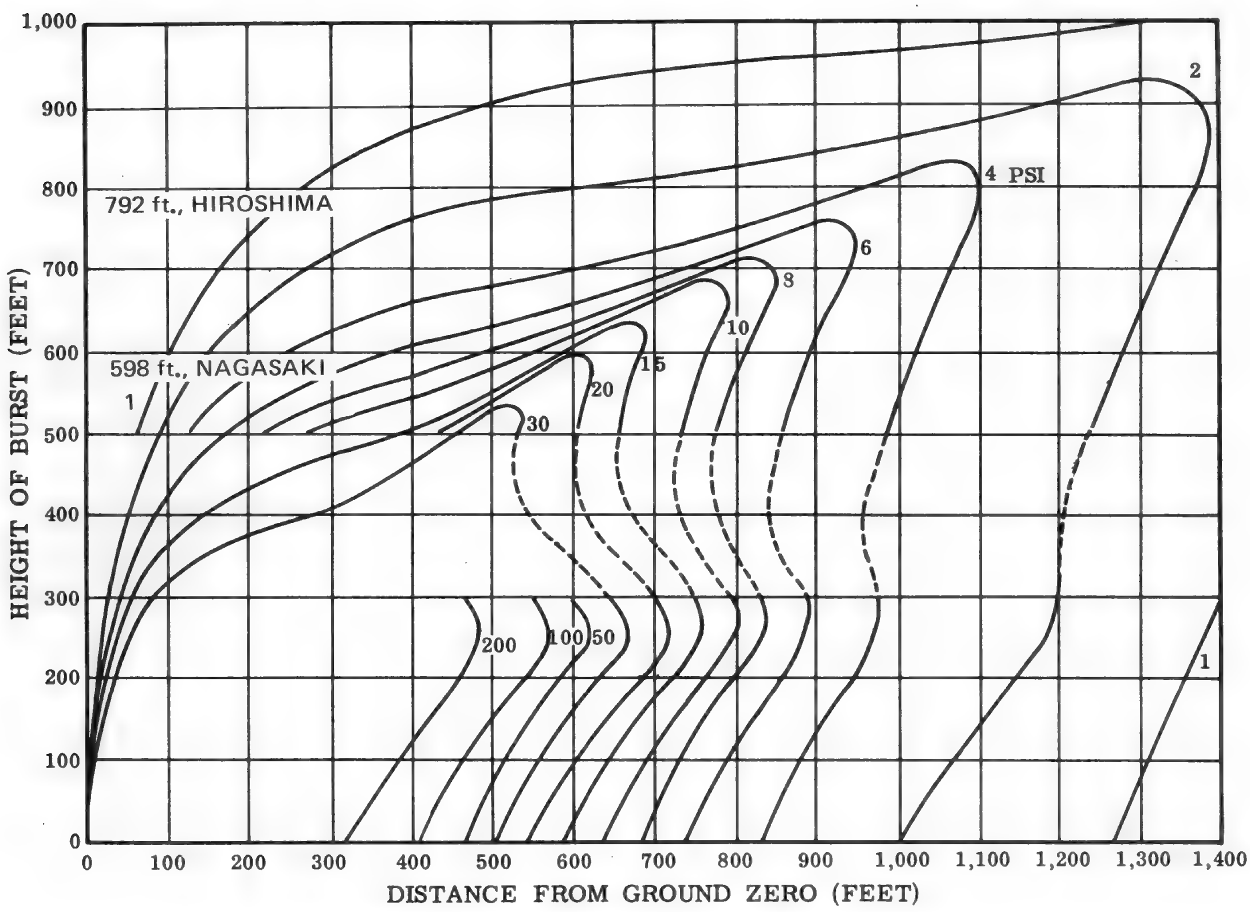


FIGURE 6-13. HORIZONTAL COMPONENT OF PEAK DYNAMIC PRESSURE FOR 1-KILOTON BURST

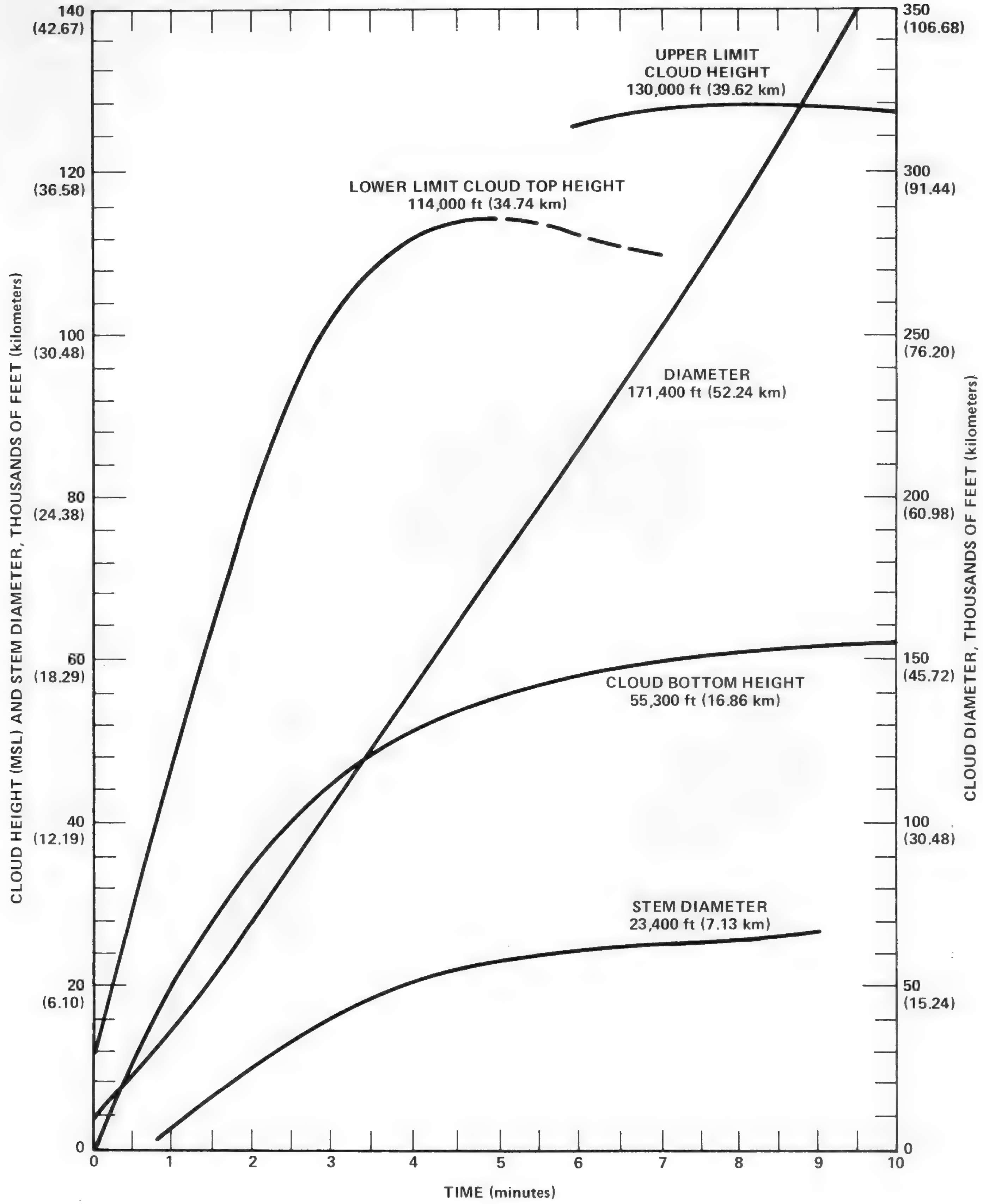


FIGURE 6-23. SHOT BRAVO - CLOUD DIMENSION

BRAVO fallout conditions. (Figures 7-17 and 7-18, Eniwetok and Bikini.)

The Department of Defense had marshaled an extensive fallout measurement program for REDWING, and it appeared risky to dedicate all that effort to the ZUNI event, knowing that any event might fail. I made a recommendation to CJTF-7, Admiral Hanlon, that another nuclear test, specifically the UCRL TEWA shot (a development companion to ZUNI with different amounts of fission) be moved from deep Bikini lagoon water to a position as close to the north Bikini reef as possible. Detonated in shallow lagoon water, the coral reef material would enhance the formation of local fallout from the TEWA event. After a brief consultation between Admiral Hanlon and Bill Ogle, the recommendation was accepted and put into the REDWING operational plans. (Figure 7-19, REDWING participation certificate.)

OPERATION REDWING--1956 PACIFIC PROVING GROUNDS

Operation REDWING was a 17-detonation nuclear weapon test series (see Table 7-5) held at the Atomic Energy Commission's Pacific Proving Grounds in the spring-summer of 1956. The REDWING series was planned primarily to test high-yield thermonuclear devices that could not be tested in Nevada. The development and testing of these devices, which generate their explosive power through the fusion or joining of hydrogen atoms, began in the U.S. in 1950 and advanced to the stage that one of the nuclear weapons tests planned for REDWING--the CHEROKEE event--would be dropped from a B-52 Strategic Air Command (SAC) bomber. This thermonuclear bomb drop was seven months after the Soviet Union had dropped its own H-bomb from a strategic bomber.

The U.S. CHEROKEE event, although sponsored as a nuclear weapons effects event by the Department of Defense, was probably more a demonstration to the world of the aircraft deliverability of U.S. H-bombs than an experiment. I watched the CHEROKEE event along with a group of 15 U.S. newsmen, the first such group invited to view a Pacific nuclear weapon test since 1946 (Bikini ABLE-BAKER, see Chapter 2).

Further American nuclear weapon testing was absolutely necessary, Strauss, Chairman AEC, told Eisenhower, as plans progressed in early 1956 for the spring-summer Operation REDWING. One of the objectives of those tests was a new H-bomb configuration that would fit into a strategic bomber (see Figure 6-24, Mark-17, H-bomb). Another objective was a smaller warhead to fit into the nose cone of an Inter-Continental Ballistic Missile (ICBM). Eisenhower was very hesitant, but when in March 1956, the Soviets undertook another series of nuclear tests, the President gave his final approval to conduct Operation REDWING. In doing so, Eisenhower pointed out in his 25 April 1956 news conference that without the H-bomb, the guided missile (ICBM), would amount to nothing, and if we stopped nuclear tests, then we would have to stop work on the missiles. (Q)

I stopped over in Honolulu on my way to the Pacific Proving Grounds for the REDWING nuclear tests and read in the local newspapers of President Eisenhower's news conference of 25 April 1956. The first question by the newsmen concerned nuclear testing and disarmament issues. Most of us were appalled by Stassen's discussions with Khrushchev in London on disarmament issues before the negotiations had even begun. (Table 7-6, President's news conference.)

Operation REDWING was the sixth nuclear weapon test series to be conducted by the United States in the Marshall Islands. During the fifth series in 1954 a serious fallout contamination incident occurred (CASTLE BRAVO, see Chapter 6) that involved not only U.S. personnel, but also Marshall Islanders and Japanese fishermen. Because of the unfavorable effect of this 1954 incident on world opinion, the U.S. government recognized the need to issue a statement that specifically addressed health and safety concerns. A draft press release was widely circulated in the AEC and DOD for our comments in early April 1956. The joint DOD-AEC press release was

(Q) Soviet Union Nuclear Tests - spring 1956:
21 March 1956, atmospheric test, detonated a few days before, announced by AEC.
2 April 1956, atmospheric test, detonated a few days before, announced by AEC.

In May 1956, members of a University of California Regents committee accompanied E.O. Lawrence to the Pacific Proving Grounds to review the ZUNI hydrogen-fusion nuclear weapon test. Left to right are: University of California Vice-President James H. Corley; UCRL Physicist Harry Keller; Regents Gerald Hagar and Victor R. Hansen; UCRL Physicists William McMaster and Gerald Johnson, in front of Brigadier General Alfred D. Starbird (person to Starbird's right is unknown); Ernest O. Lawrence; UCRL Physicists Carl Haussmann and Charles Blue; UCRL Director Herbert York; Regent Earl J. Fenston.

FIGURE 7-23. UCRL GROUP AT PACIFIC PROVING GROUNDS

that the CHEROKEE shot was off target somewhere to the northeast of Charlie island. He had arranged for a helicopter to take me, Colonel Woodward, and an H&N engineer with a surveying transit to go up island to try and triangulate the actual burst point, which was out to sea some place. We stopped at several islands east of Charlie, and it was noticed that the Air Force structures were still standing, but with some sidings removed to the north. Finally, on Charlie island it was apparent from various blast indications that the burst had occurred about 20,000 feet (about 4 miles) to the northeast. On return to Nan island, we prepared a message for Gaelen to send over to Headquarters JTF-7 at Eniwetok. (Figure 7-25, Gaelen Felt.)

I knew the message on the CHEROKEE bombing error would be forwarded by Admiral Hanlon to the Joint Chiefs of Staff in Washington. I also knew that my friend, Don Quarles, Secretary of the Air Force would be disappointed in the turn of events. He would probably have to go over to the White House and inform Eisenhower of the situation. I made a mental note to go by and talk to Don as soon as I got back to Washington and explain that Brigadier General "Blackie" Samuels had been on the radio to the drop aircraft continuously during the bombing run, giving direct orders to the bombardier.

A couple days after CHEROKEE, we were amused by the newspaper accounts of the shot, which described it as being "the largest ever conducted in the Pacific." Unclassified accounts of CHEROKEE surmised that the yield was 10 MT, which was fine with all of us who knew the actual explosive power, and we hoped that impressed Khrushchev.

ZUNI Event

ZUNI was a test of a large yield thermonuclear device, designed and developed by UCRL, that required an island to support the large amount of diagnostic instrumentation. Real estate was scarce in the Pacific Proving Grounds, ZUNI being the one event at Bikini to crater out a piece of the island on Operation REDWING. Because of its yield and island configuration, ZUNI was the primary event for fallout documentation on the operation. ZUNI event would turn out to be the most thoroughly documented fallout shot measured during all the United States' weapon

FIGURE 7-24. OPERATION REDWING CHEROKEE SHOT

FIGURE 7-25. GAELEN FELT

testing in the Pacific from 1946 (Bikini ABLE/BAKER) through 1962 (Operation DOMINIC).

About two weeks before the readiness date for ZUNI, we toured the shot island (Tare) and the shot cab with Walter Gibbins, UCRL Deputy on Task Group 7.1 (Appendix B, 7.1 organization). It was interesting to walk the area and note that ZUNI ground zero was near the old KOON crater produced by a UCRL event on Operation CASTLE. (Figure 7-26, ZUNI cab.)

Reviewing the fallout documentation plans for ZUNI shot, I spent some time on one of the three fallout collection ships that had been modified by the U.S. Naval Radiological Defense Laboratory (NRDL) at Hunters Point in the San Francisco bay area. With Commander Don Campbell, Program 2 Director, we visited the YAG-39 (USS George Eastman) which had been modified to permit operations in the fallout area from its heavily

shielded control room and was to be positioned in the fallout zone (along with the YAG-40 and USS Crook County) prior to arrival of fallout. It was only after spending some time on one of the YAGs that I appreciated the potential contributions that ships could make in our all-out effort to document fallout from large yield thermonuclear weapon explosions. Paul Tompkins and Gene Cooper, heads of NRDL, and I reviewed their plans both in my office and in theirs for modifying the ships for fallout collection. I was more impressed with the AFSWP costs and long lead times for modifications in the naval ship yards. Out in the Pacific, the modified ships were truly technological innovations. Victor Van Lint spent a large part of his time out in the Pacific coordinating the plans for the Scripps Institute of Oceanography's boat (the MV Horizon) to service the 16 deep moored "skiffs" that were instrumented to collect fallout data in the area north of Bikini Atoll.

As shot day for ZUNI event approached, everyone was evacuated from Bikini Atoll, including those who had occupied the Control Point on Nan island during the CHEROKEE shot. The Task Group 7.1 Command staff and key scientific personnel were aboard the USS Curtiss when ZUNI was detonated by a radio signal at 5:56 a.m. on 28 May 1956. Ground zero was near the KOON crater that was made on Operation CASTLE. The yield of the University of California Radiation Laboratory (UCRL) ZUNI device was 3.5 MT. ZUNI, with its high yield and surface placement, formed a large crater that chewed out the western end of Tare island, and ejected material was pulled up into the radioactive cloud. As soon as we were able to make an aerial survey of the ZUNI crater, it was flooded by the lagoon waters. Crater dimensions were: radius = 1165 feet, depth = 93 feet (Figure 7-27, ZUNI shot).

The ZUNI radioactive cloud topped at 85,000 feet, with a diameter at that time of 75,000 feet. General cloud movement was to the north at 15 knots, but the lower portion of the stem moved to the west, under the prevailing easterlies, at about the same speed. The 30,000-foot winds turned to the southeast sometime late on shot day, causing light fallout on atolls southeast of Bikini. Heavy radioactivity was measured throughout most of the Bikini Atoll, with readings of 75 R/hr at 4 hours (H+4 along the northern rim of islands). Fortunately, the living area on Nan was only lightly touched by fallout. An H+4 value of 0.003 R/hr was measured. Fallout contours for the ZUNI event are given in Figure 7-28, with all readings being extrapolated back to H+1 hour. Some hot spots of 150 R/hr were noted at about 50 miles north of the shot point. (Figure 7-28, fallout contours, and Figure 7-29, ZUNI crater.)

TEWA Event

(See Figure 7-30 and 7-31, Eniwetok and Bikini Atoll maps for shot locations.)

The UCRL 5 MT TEWA device was fired 21 July 1956 on a barge anchored on the reef between Charlie and Dog islands on the north rim of Bikini Atoll (Figure 7-32,TEWA barge). TEWA was a companion event to ZUNI for documentation of fallout from large yield thermonuclear weapons (Figures 7-33 and 7-34, TEWA device and shot cloud). In early Operation REDWING planning, the location of the TEWA event had been moved from deep lagoon waters to as near the coral reef as possible. I had always hoped that it could be anchored in water that was less than the 24.7 feet which occurred on the final placement. Total weight of the barge was 440,000 pounds, including 410,000 pounds of steel, all of which contributed to the fallout material, as well as the coral reef material created by the explosion. Crater measurements were: radius = 1915 feet, depth = 133 feet, with a total of 740 million cubic feet of material being ejected in the formation of the crater. The fallout pattern documented for TEWA is given in Figure 7-35. While the yield of TEWA (5 MT) was larger than ZUNI (3.5 MT), it was observed that the down wind "hot spot" for TEWA (1000 R/hr) was much higher than on ZUNI (150 R/hr). The difference was primarily due to the higher percentage of fission yield for TEWA as compared to ZUNI. (Figure 7-35, TEWA fallout contours, and Figure 7-36, TEWA crater.)

SEMINOLE Event

The SEMINOLE device was detonated on the western end of Irene island (Eniwetok Atoll) at 12:55 p.m. on 6 June 1956 during Operation REDWING. SEMINOLE was a LASL sponsored event with a low yield of 13.7 KT. However, because the device was detonated within a large water filled tank, it probably had an increased

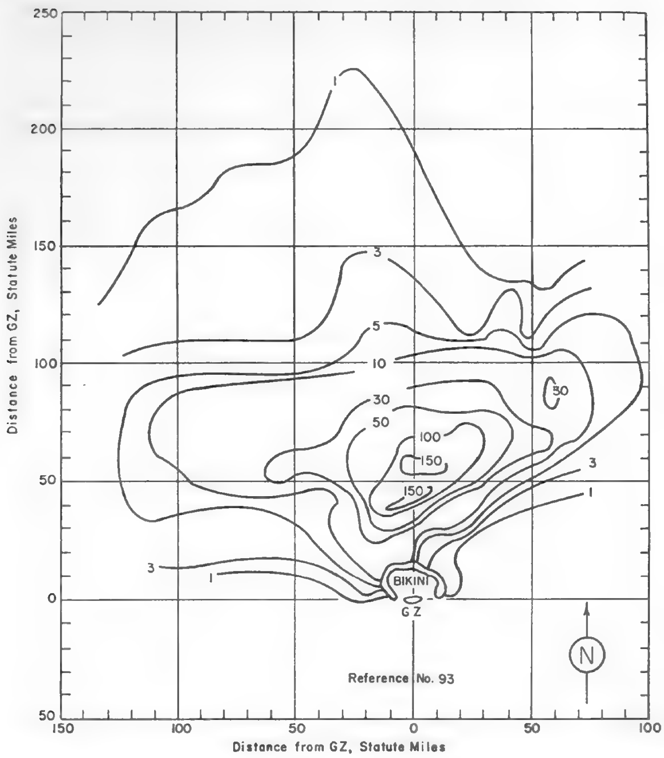


FIGURE 7-28. ZUNI FALLOUT CONTOURS

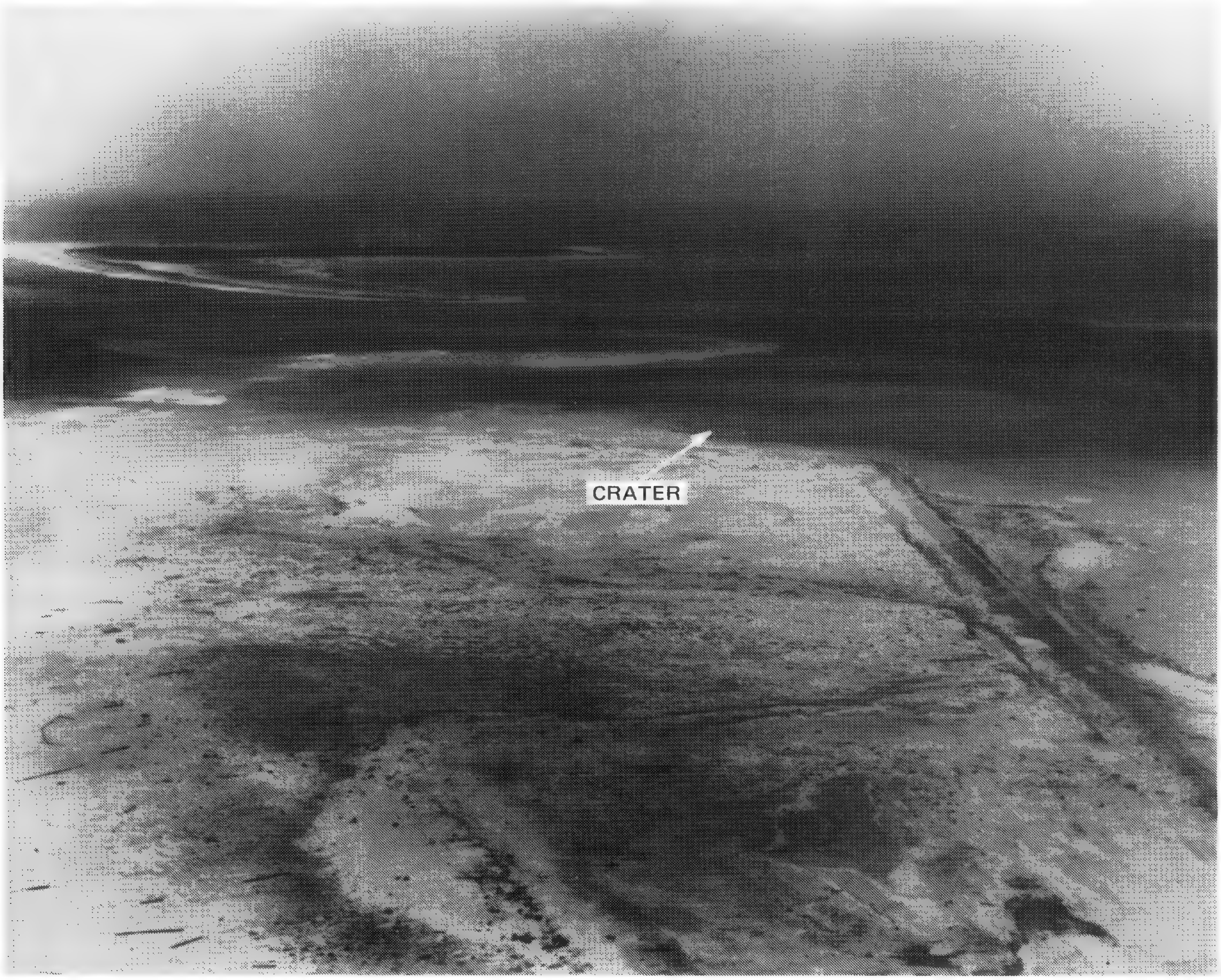


FIGURE 7-29. ZUNI CRATER (H + 10, LOOKING WEST)

FIGURE 7-32. TEWA PRE-SHOT BARGE (D-1, BIKINI LAGOON BETWEEN DOG AND CHARLIE ISLANDS)

FIGURE 7-33. TEWA DEVICE (D-3, HOB = 8.2' ABOVE WATERLINE)

MAY 10 1957

SCIENTIST DOUBTS FALL-OUT DANGER

Atom Tests Can Be Safe for 40 Years at Present Rate, Pentagon Aide Testifies

NY TIMES

Special to The New York Times.

WASHINGTON, May 9 — Atomic testing can be continued at the present rate for another forty to fifty years and not create any serious danger from radioactive fallout, the chief atomic weapons scientist in the Defense Department believes.

This opinion was offered recently by Dr. Frank H. Shelton, technical director of the Armed Forces Special Weapons Project. He gave it when testifying before a House Appropriations subcommittee on the possible dangers to human health caused by the fall-out from atomic explosions. The testimony was released today.

Dr. Shelton was called before the subcommittee to discuss what had been described as a "great deal of concern" being expressed over the long-range effect on the human race of the fall-out. The subcommittee's chairman, Representative George H. Mahon, Democrat of Texas, had noted such "concern."

At one point during the closed door hearing, Mr. Mahon asked:

"Could you not say that at the present rate we could go on for forty to fifty years without serious danger in so far as you know?"

"Yes,"Dr. Shelton replied.

Information 'Meager'

At the same time, Dr. Shelton conceded that information on world-wide fall-out from past atomic tests was "extremely meager." The Defense Department, he said, is taking steps to define more precisely the amount of radioactive debris in the air from atomic tests and the rate at which it is falling to the earth.

Dr. Shelton testified that it would require large nuclear explosions with a yield equivalent to 30,000,000,000 tons of TNT to bring the average concentration of Strontium-90 in human bones up to the maximum permissible concentration. This would be equivalent to 1,500,000 atomic bombs of the size dropped on Japan in World War II.

Strontium-90 is a long-lived radioactive product of a nuclear explosion. In human bones it can produce cancer or leukemia. The maximum permissible concentration of Strontium-90 for general populations has been set at one-tenth of a microcurie for a person. A curie is a technical measurement of radiation, and a microcurie is one-millionth of a curie.

Dr. Shelton said that the maximum permissible concentration was five to ten times below the concentration necessary to produce a "barely detectable increase" in the rate of bone cancer or leukemia. His statement was based on the assumption, challenged by some scientists, that extremely small doses of Strontium-90 will not induce bone cancer.

Dr. Shelton likewise tended to minimize the threat of external radiation from fall-out materials. To increase the world-wide external radiation exposure by 10 per cent, he said, would require atomic explosions with a yield equivalent to 5,000,000,000 tons of TNT. The 10 per cent increase, he said, would be equivalent to the greater natural radiation received as a result of living in Denver instead of at sea level.

In the event of war, Dr. Shelton said, exposure to radioactive fallout can be reduced "very effectively" by even the most simple shelter.

FIGURE 8-4. NEWSPAPER ARTICLE, NEW YORK TIMES, 10 MAY 1957, "SCIENTIST DOUBTS FALLOUT DANGER"

'BRAVO' WAS 66 MILES WIDE

MAY 1 0 1957

H-Test a Close Squeak for Marshall Islanders

WASHINGTON NEWS

Sixty-four Marshall Islanders dusted with "Bikini ashes" from the big H-bomb test of March 1, 1954, are alive today only because they lived on the south side of their native atoll.

If they had lived some 40 miles to the north, all would now be dead. As it was, all suffered radiation injury but have now recovered—as far as detectable effects are concerned.

This and much more about the so-called "Bravo Shot" of the 1954 H-bomb tests in the Pacific was disclosed for the first time in testimony released today by a House appropriations sub-committee.

The revealing testimony was by Dr. Frank H. Shelton, technical director of the Armed Forces Special Weapons Project.

Altho some of the facts reported by Mr. Shelton had been known to reporters, they never had been publicly stated before by any official. For example:

15,000,000 TONS

The power of the March 1, 1954, explosion was "on the order of" 15 megatons, or 15 million tons of TNT.

The Bravo bomb cloud rose to 100,000 feet. Its diameter was 66 miles. The cloud stem was 6½ miles thick.

This was the extremely "dirty" bomb that alerted the world to the menace of radioactive fallout. In all, 239 Marshall Islanders living on atolls east and southeast of Bikini suffered radiation injury.

The worst afflicted were 64 inhabitants of Rongelap, the nearest atoll to Bikini. They lived only on the southern side of their atoll, which is roughly 40 miles in its north-south dimension.

About six hours after the Bravo explosion, "hot" fallout in the form of visible flakes began to fall on Rongelap. By the time their plight was detected, the Rongelapese had been exposed to about 175 Roentgens of radioactivity. It takes about 450 roentgens to kill.

According to Dr. Shelton, if the natives had lived on the north side of their atoll, where the fallout was more intense, "all would have died."

'CLEANER' BOMB

President Eisenhower, Defense Secretary Charles E. Wilson, and AEC Chairman Lewis L. Strauss subsequently reported development of "cleaner" H-bombs.

FIGURE 8-5. NEWSPAPER ARTICLE, WASHINGTON NEWS, "H-TEST A CLOSE SQUEAK FOR MARSHALL ISLANDS"

5-12-57

64 Islanders Dusted By Ashes -- Alive

WASHINGTON (UP)—Sixty-four Marshall Islanders dusted with "Bikini ashes" from the big H-bomb test of March 1, 1954, are alive today only because they lived on the south side of their native atoll.

If they had lived some 40 miles to the north, all would now be dead. As it was, all suffered radiation injury but have now recovered—as far as detectable effects are concerned.

This information about the so-called "Bravo Shot" of the 1954 H-bomb tests in the Pacific was disclosed for the first time in testimony released today by a House Appropriations Subcommittee.

The revealing testimony was by Dr. Frank H. Shelton, technical director of the armed forces special weapons project, which plays an important role in development and testing of atomic arms.

Although some of the facts reported by Shelton had been known to reporters, they never had been publicly stated before by any official.

Bravo was the extremely "dirty" bomb that alerted the world to the menace of radioactive fallout. In all, 239 Marshall Islanders living on atols east and southeast of Bikini suffered radiation injury.

The worst afflicted were 64 inhabitants of Rongelap, the nearest atoll to Bikini. They lived only on the southern side of their atoll, which is roughly 40 miles in its north-south dimension.

According to Shelton, if the natives had lived on the north side of their atoll, where the fallout was more intense, "all would have died."

FIGURE 8-6. NEWSPAPER ARTICLE, WASHINGTON NEWS, "64 ISLANDERS DUSTED BY ASHES - ALIVE"

Not All People Would Be Doomed By Atom Fallout

WASHINGTON (UPI) — A defense expert sought today to quiet fears that worldwide fallout from large-scale nuclear war would doom all peoples.

"Even for a very large-scale war," he said, "the worldwide hazard to the countries not attacked would not be very important in terms of their survival."

The expert was Dr. Frank Shelton, 34-year-old technical director of the Defense Department's atomic support agency. He testified before a congressional atomic energy subcomittee at hearings intended to show the world what its fate would be if East and West should trade heavy nuclear blows.

Shelton made it clear that noncombatant countries close enough to the target nations to be caught in short-term local fallout might suffer greatly. But the straospheric fallout, which hangs in the high atmosphere for periods up to several years, would not threaten the survial of everybody, he said.

Shelton detailed the terrific damage that would be done to target areas by heat, blast, prompt radiation, and local fallout. His figures have been published before. They add up to fantastic disaster.

But Shelton appeared unimpressed by the worldwide menace of long-lasting nuclear fallout such as would be generated by a war with H-bombs. He said 1,000 megatons would bring the level of strongium-90, the cancer-causing principal villain of stratospheric fallout, up to about the maximum permissible level in the northern hemisphere.

The genetic dose, inflicted upon the cells of heredity, would not be much greater than the existing natural background dose, he said.

Sen. Clinton P. Anderson (D-N.M.), chairman of the full joint atomic committee, took sharp issue with Shelton about the worldwide hazard until the witness explained he was not referring to local fallout. This consists of radioactive particles which come down in a matter of hours, days, or weeks after an explosion.

Anderson asked Shelton if he was telling countries like France and Belgium "not to worry" if the United States and Russia traded hydrogen punches.

Shelton made it clear that if they got caught in local fallout patterns they would be in trouble.

FIGURE 8-10. "NOT ALL PEOPLE WOULD BE DOOMED BY ATOM FALLOUT," CONGRESSIONAL TESTIMONY BY DR. FRANK SHELTON, 7 JUNE 1957

the Oval Office of the White House for 24 June 1957. Members of the Presidential briefing team that Strauss had assembled were all from the University of California Radiation Laboratory (UCRL, the second nuclear weapons design laboratory): Ernest Lawrence, Mark Mills, and Edward Teller. It was probably Mark Mills' idea to brief the President, following the sharp exchange between Senator Anderson and General Starbird at the recently concluded "fallout" hearings. Conspicuous by their absence from the Presidential briefing were the Los Alamos weapon designers. After all, it was the "clean" NAVAJO shot on Operation REDWING (1956), designed by LASL, that established the state-of-the-art in reduced fission weapon designs.

"We now believe that we know how to make virtually clean weapons, not only in the megaton range, but all the way down to small kiloton weapons," Lawrence told the President. *"It will take considerable time and effort to do this, but if we were to fail to develop such weapons and to convert our existing weapons, then--if the 'dirty' weapons should be used in war--our failure could truly be called a crime against humanity."*

Teller added to the argument:

"We have started some thinking on how to make atomic explosions for peaceful purposes. Clean thermonuclear weapons could be detonated in deep caverns to produce steam, to break up taconite ore, to release oil from oil strata, to cut through large Earth barriers and modify the flow of rivers, and perhaps even to modify the weather on a broad basis through changing the dust content of the air."

Teller's "peaceful purposes" theme, at the Presidential briefing, had been given a major boost by the inclusion of the "RAINIER shot" as a fully contained underground experiment into the 1957 Operation PLUMBBOB list of approved shots. Ed Teller, UCRL, and Dave Griggs, of the Rand Corporation, had begun in early 1956 a

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HARDTACK CRATERING:

computer numerical simulation calculation (D.E. Burton, et al, Lawrence Livermore Radiation Laboratory, August 1984) using a multiphase constitutive model that accounts for pore pressure and porous flow of fractured Eniwetok coral showed that the size and shape of the KOA crater could be accounted for by subsidence and liquification phenomena. The model produced a crater having 95 percent of the measured volume of the KOA crater. (Figure 9-11, Pacific Craters.)

A decade ago, and earlier, the few attempts to numerically simulate high yield, surface burst nuclear explosions did not produce crater calculations that were consistent with the observed size and shape of the Pacific Proving Ground craters. Corresponding calculations for reasonable stiff geologic media (such as that representative of the Soviet Union missile silo sites) indicated crater ejecta volumes that were smaller than the Pacific Proving Ground empirical data by factors of 40 to 100. For example, in 1975 (J.C. Trulio of Applied Theory Inc.) the calculations of a 1-MT surface burst in stiff geology gave an ejecta crater of about 1,000 - 1,225 feet radius, and much deeper than the 1.4-MT KOA crater (2,160 feet radius, 170 feet depth) in coral reef material.

At that time, Air Force Strategic Air Command (SAC) and the Joint Strategic Target Planning Staff (JSTPS) discounted such calculations in favor of using the empirical evidence of the Pacific Proving Ground craters for Soviet Union strategic targets, using a kill criterion of less than a crater radius. Even at the late date of 1985, the "Capabilities of Nuclear Weapons," a classified document (Effects Manual-1) and the "Air Force Manual for Design and Analysis of Hardened Structures," are widely used references that illustrate the dependence on using Pacific Proving Ground empirical crater dimensions. (8)

A summary of empirical crater dimensions from detonations at Eniwetok and Bikini Atolls and the Nevada Test Site is given in Table 9-2. A relative simple criterion for assessing the shape of a crater is the ratio of its radius (R) to depth (D), or R/D, which is always about two for most ejecta craters produced by high explosives, nuclear weapons and meteor impacts on the moon and the planet Mercury a notable exception being the large-yield Pacific craters.

CACTUS Event And Its Crater

Colonel "Ted" Parsons (USAF), Armed Forces Special Weapons Project Deputy for Department of Defense Programs on the Joint Task Force-Seven staff, piloted the small, single engine liaison aircraft as we flew from Eniwetok (Elmer) Island to Runit (Yvonne) Island for a walking tour of the CACTUS shot area on 18 April 1958--a little over two weeks before it was scheduled to be detonated. As we approached Runit Island, the large Cactus ground zero shot cab structure and the radiating diagnostic line-of-sight pipes and tunnels were clearly evident. (Figure 9-12, CACTUS Shot Area.)

I mentioned to Ted that the old LACROSSE crater (REDWING-1956) looked about the same as it did when we flew up a few hours after it was created. After landing on Runit, we walked to the blast line, and I took careful note of the "Q-gauges" that had been mounted to measure the blast dynamic pressures on CACTUS, which should have been nearly "ideal" values for a surface burst. The large drum gauges to measure air-ground interface pressures near the crater edge had been installed about a month previously. (Figure 9-13, picture taken the next day upon request; Figure 9-13a, Q-Gauges; Figure 9-13b, Drum Gauges .)

The CACTUS ground zero building was constructed of steel frame, 33 by 34 by 30 feet high, with a black corrugated protective metal roof and sides and a 6-inch concrete slab floor. The nuclear device was mounted 3 feet above the floor with massive asymmetric sand-filled concrete baffles around the weapon that were 13 feet high. The construction weights for the CACTUS GZ station, excluding the foundation, were: concrete, 200,000 pounds; coral sand, 55,000 pounds; and structural & rebar steel, 87,000 pounds (9: see Figure 9-8.)

The CACTUS device was detonated 596 feet southwest of the LACROSSE ground zero at 0615 hours on 6 May 1958 with a yield of 18 KT. The CACTUS crater dimensions were: radius = 173 feet; depth at GZ = 34.5 feet, and maximum depth = 37.2 feet; crater lip height = 8 to 14 feet (see Table 9-2). (Figure 9-14, CACTUS Crater.)

There was an effort in 1979-1980 to clean up the residual radioactive materials present on

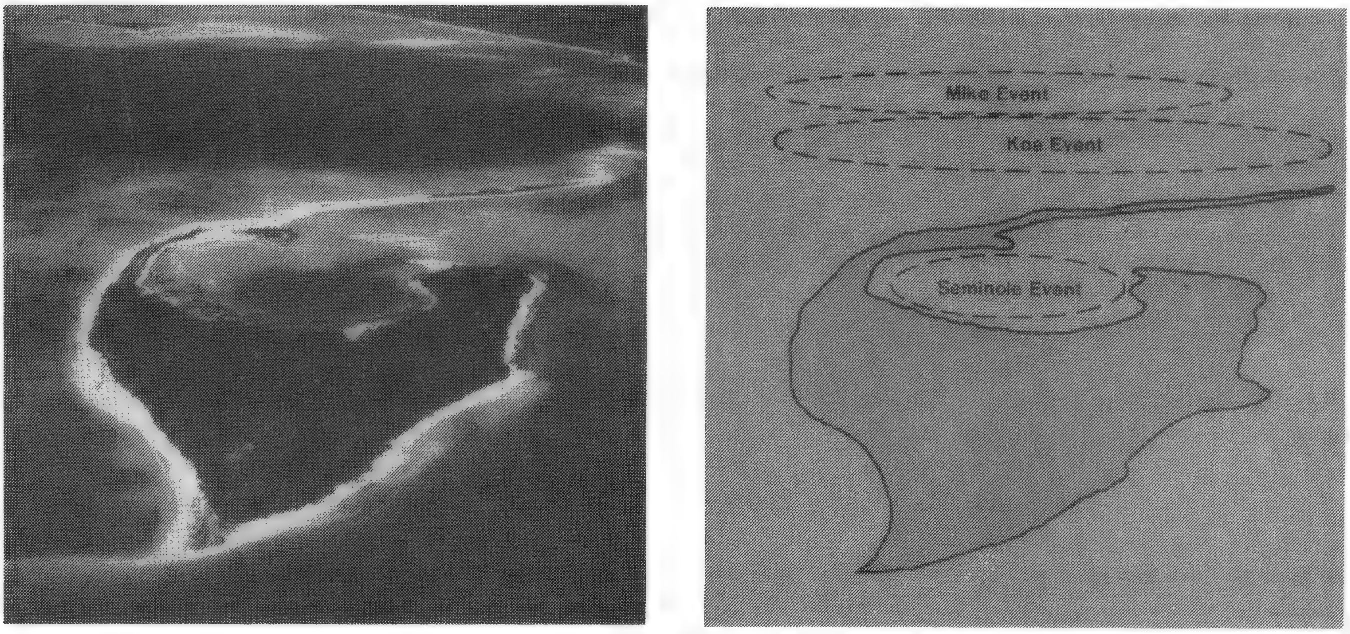


FIGURE 9-11a. PACIFIC CRATERS IN THE MARSHALL ISLANDS, CRATERS PRODUCED BY SOME U.S. NUCLEAR TESTS AT THE PACIFIC PROVING GROUND IN THE MARSHALL ISLANDS

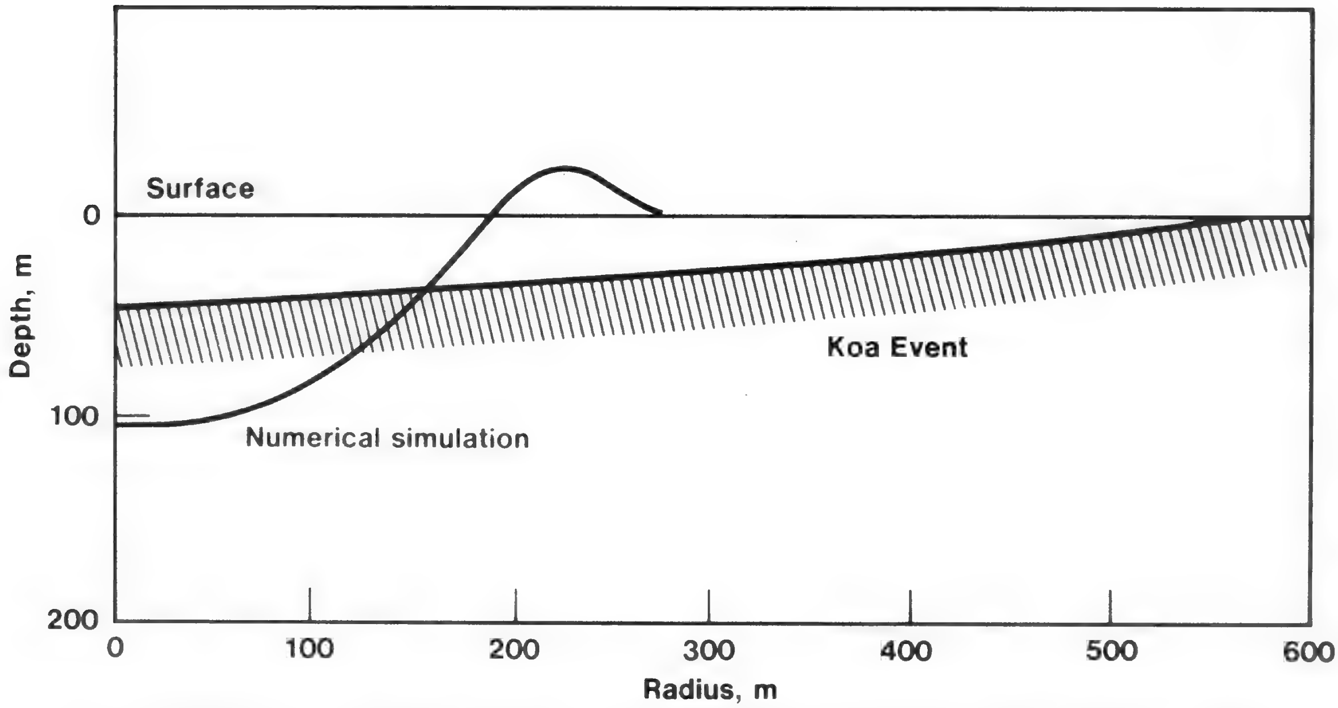


FIGURE 9-11b PACIFIC CRATER CALCULATIONS, PROFILE OF THE PACIFIC PROVING GROUND CRATER PRODUCED BY THE KOA EVENT, CONTRASTED WITH THE CRATER RESULTING FROM A TYPICAL NUMERICAL SIMULATION

TABLE 9-2. CRATER DIMENSIONS FROM DETONATIONS AT ENIWETOK AND BIKINI ATOLLS AND NEVADA TEST SITE

OPERATION	EVENT	YIELD (KT)	HOB (FT)	RADIUS (FT)	DEPTH (FT)	RADIUS / DEPTH
CRATER DIMENSIONS FROM TEST EVENTS AT ENIWETOK AND BIKINI ATOLLS						
IVY (1952)	MIKE	10,400	10.0	2910	187.0	15.6
CASTLE (1954)	BRAVO	15,000	7.0	3255	250.0	13.0
	KOON	110	9.6	495	40.0	12.4
REDWING (1956)	LACROSSE	40.0	9.6	200	55.5	3.6
	ZUNI	3,500	10.0	1165	113.0	10.3
	SEMINOLE	13.7	7.0	324	32.2	10.1
	TEWA	5,000	10.0	1915	133.0	14.1
HARDTACK I (1958)	CACTUS	18.0	3.0	173	37.2	4.65
	KOA	1,370	2.7	2160	170.0	12.70
	OAK	8,900	5.8	2870	204.0	14.70
	FIG		1.5	18	9.7	1.86
CRATER DIMENSIONS FROM TEST EVENTS AT NEVADA TEST SITE						
BUSTER JANGLE (1951)	SUGAR	1.2	+3.5	45	21	2.10
	UNCLE	1.2	-17	130	53	2.45
TEAPOT (1955)	ESS	1.0	-67	146	96	1.6
NOUGAT (1962)	SEDAN	104	-635	640	320-	2.0

various contaminated islands in Eniwetok Atoll as a result of nuclear weapons testing through Operation HARDTACK in 1958. Although there had been over twenty years of time for the radioactivity of the fission particles to decay, the most troublesome isotope to still contend with in the clean-up was cesium-137, which has a half-life of thirty years. About 110,000 cubic yards of radioactive soil was gathered up from the various islands and dumped into the CACTUS crater. To stabilize the contaminated material, the crater was first lined with a water tight material; and after filling with the fission debris and other radioactive materials, an eighteen-inch thick concrete "dome" was constructed over the top of the material that filled the crater. (Figure 9-15, CACTUS Dome.)

KOA Event

The KOA nuclear device was detonated 13 May 1958 in a water tank at the west end of Gene Island, at the north end of Eniwetok Atoll, near the old IVY MIKE crater created in 1952. The KOA ground zero building consisted of a 10-foot in diameter, 8 foot high, air-filled steel tank containing the nuclear weapon 3 feet above the floor. The air-filled tank was located concentrically inside a 30-foot in diameter water filled tank 23 feet high. The concrete foundation weighed 278,000 pounds and there were 70,000 pounds of steel in the water tanks. When filled, there were 870,000 pounds of water surrounding the nuclear detonation. (10: Sea-Floor Observation)

The KOA yield was 1.37 MT and produced a crater with a radius (R) of 2160 feet and a depth (D) of 170 feet, giving an R/D of 12.7 (see Figure 9-11, Oblique of SEMINOLE, KOA, and MIKE craters). At the edge of the KOA crater was an Air Force concrete beam experiment 1830 feet from ground zero inside of what appeared to be the crater radius (see Figure 9-16, pre-shot beam). After the shot, the top of the concrete beam experiment was 6.5 feet lower than pre-shot

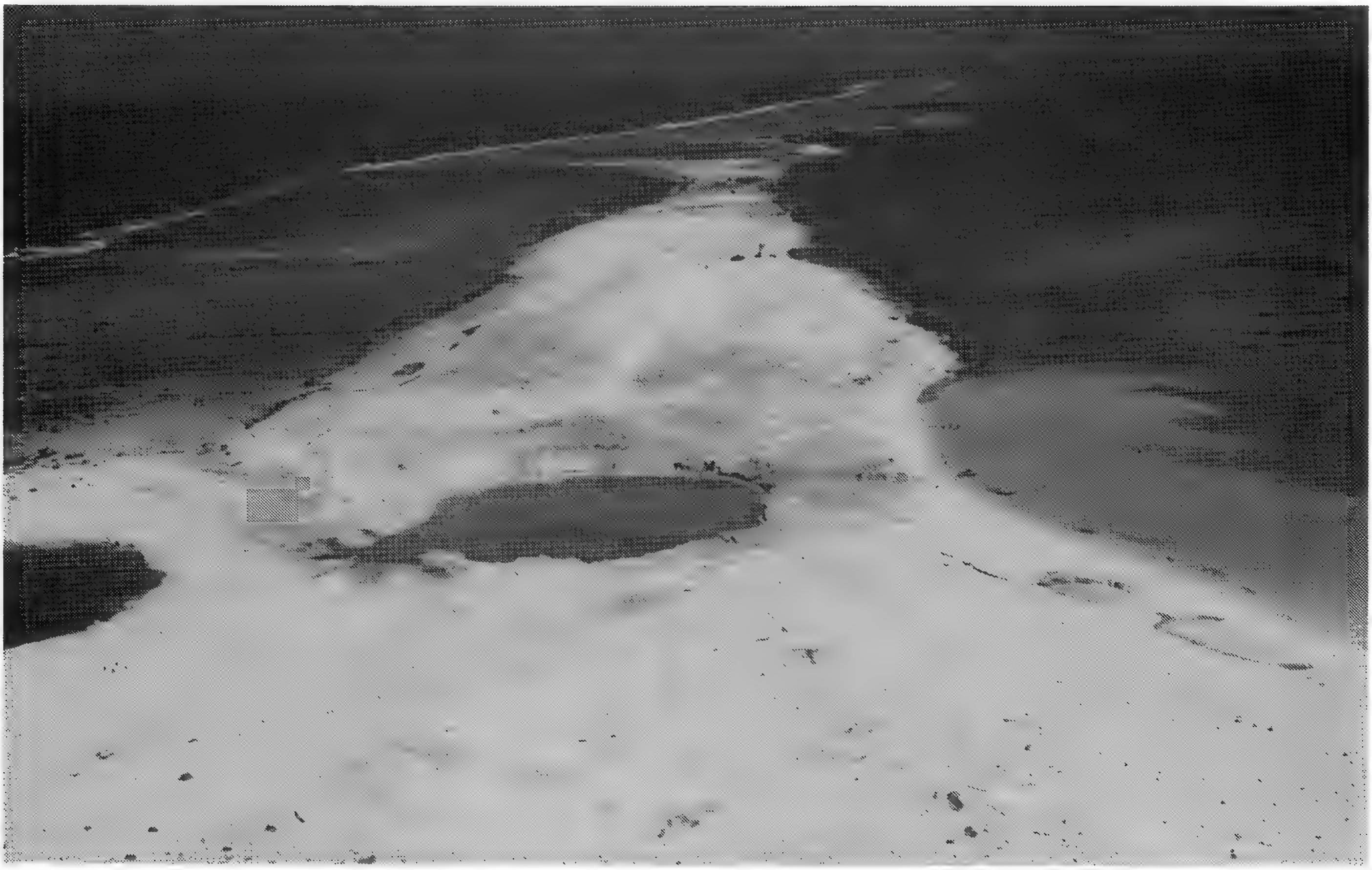


FIGURE 9-14a. HARDTACK, SHOT CACTUS, SURFACE BURST, H + 3

FIGURE 9-14b. HARDTACK, SHOT CACTUS, ENIWETOK ATOLL, PHOTO: D + 3, VIEWING S., (LACROSSE CRATER ON LEFT)

The New York Times March 20, 1959

Argus Weaponeer

Frank Harvey Shelton

Special to The New York Times.

WASHINGTON, March 19—For a few minutes today Dr. Frank Harvey Shelton stepped out of the anonymity that goes with his role as the Pentagon's chief atomic weaponeer. From the way the young, retiring scientist nervously wet his lips, it was apparent that he did not like the unaccustomed glare of publicity.

Man in the News

As technical director of the armed forces special weapons project, Dr. Shelton is the principal Defense Department scientist responsible for developing military requirements for atomic weapons and for conducting atomic tests.

As project director he was also responsible for the over-all scientific direction of last summer's high-altitude explosions that created a sheet of radiation around the world.

It was the latter role that today drew Dr. Shelton out of his closely guarded Pentagon office to participate in a hectic news conference on the novel experiments of creating man-made radiation in space.

Has Little to Say

Dr. Shelton had little to say about his role in what some have called "the greatest scientific experiment of all time" and when he did talk, his low mumble was virtually inaudible to reporters.

According to the person who knows him best, his wife, this quiet, shy manner is characteristic of the 34-year-old nuclear physicist.

"He talks more than he used to," she explains, "but he still doesn't talk very much. I do most of the talking, and he gets worried when I don't talk."

The quiet manner can perhaps be attributed partly to his training as a scientist more interested in research than in conversation. As one colleague described him today, "Frank is a very studious scientific fellow."

Part of the silent attitude, however, springs from the strict secrecy that surrounds his job as an atomic weaponeer.

"We have a very tough mission," he explains, of his project, "and we just don't like publicity.

Study of Cosmic Rays

Dr. Shelton was drawn into the secrecy of atomic weapons and the spectacular creation of man-made radiation in space through a study of the cosmic rays that are mysteriously created by nature.

As a graduate student at the California Institute of Technology, he specialized in research on the particles of cosmic rays. He had originally started as an engineering student but then "grew into" the field of physics.

This research in nuclear physics—he received his doctors degree for his work in 1953—lead him into the field of atomic weaponry. He was employed by the Sandia Corporation, which carries out atomic weapons developments and manufacture for the Atomic Energy Commission. Then three-and-a-half years ago he came to the Pentagon to be the technical director of the Armed Forces Special Weapons Project (abbreviated to ASWAP within the Pentagon).

Associated Press

"We just don't like publicity."

Won a Scholarship

Dr. Shelton was born in 1924 at Flagstaff, Ariz., the son of a former schoolteacher and a worker on the Hoover Dam. Most of his boyhood was spent in Boulder City, Nev.

Through the winning of a scholarship Dr. Shelton was able to go to the California Institute of Technology. His college career was interrupted during World War II by a period of service with the Army, during which he obtained a commission and spent most of his time in school.

While still an undergraduate he married the former Miss Lorene Gregory of Trinidad, Colo., in 1948. They have three daughters, ranging in age from 5 to 9 years.

The type of man who brings work home from the office, Dr. Shelton has few interests or hobbies outside of his work. He occasionally dabbles in collecting stamps and coins, but as he explained today:

"I have no real hobbies. I just like my work."

FIGURE 10-5. ARGUS WEAPONEER

Quarles Sets Policy on Data but Bars Full Publication of the Project's Findings

Special to The New York Times

WASHINGTON, March 19—Some results of the Project Argus experiment are being prepared for publication by the National Academy of Sciences through "normal scientific channels."

This was announced at the Pentagon today by Donald A. Quarles, Deputy Secretary of Defense, in response to requests for details of the tests last summer in which three atomic weapons were detonated 300 miles above the earth.

This policy was confirmed by Dr. Alan T. Waterman, director of the National Science Foundation, and Dr. Detlev V. Bronk, president of the National Academy of Sciences.

They said the plans were "well advanced" for "orderly publication" in scientific journals. In addition, they said a symposium would be held at the National Academy's annual meeting here April 27, 28 and 29.

Mr. Quarles emphasized plans to keep many of the results of the test secret. He announced that he was sorry that the project was no longer a secret.

In response to a question about the publication of news of the tests in The New York Times this morning, Mr. Quarles said that this was not "playing the game" the way he liked to see it played.

Mr. Quarles, however, would not confirm that he was, in effect, accusing The Times of a security breach.

Publication Withheld

The tests were conducted last Aug. 27, Aug. 30 and Sept. 6. In publishing the account this morning, The Times explained that it had withheld publication of its information until it became evident that the Soviet Union knew of the theoretical principles involved and that a high official of the Pentagon had recommended an official announcement.

The Defense Department decided this morning to hold a news conference after numerous requests for information resulted from The Times' accounts.

But Mr. Quarles announced that if it had been up to him there would have been no disclosure. He made it clear to those who attended that The Times' publication of the news of the tests had not been officially inspired.

Mr. Quarles said that the experiments had been classified because: first, they had substantial military implications; second, "we were probing a new science here" and that more time was required to assess the results.

"The results are not the property of the scientists," he responded to a subsequent question on the same subject. "Of course the scientists publish those things which we collectively judge to be in the interest of the American people to publish."

FIGURE 10-6
QUARLES SETS POLICY

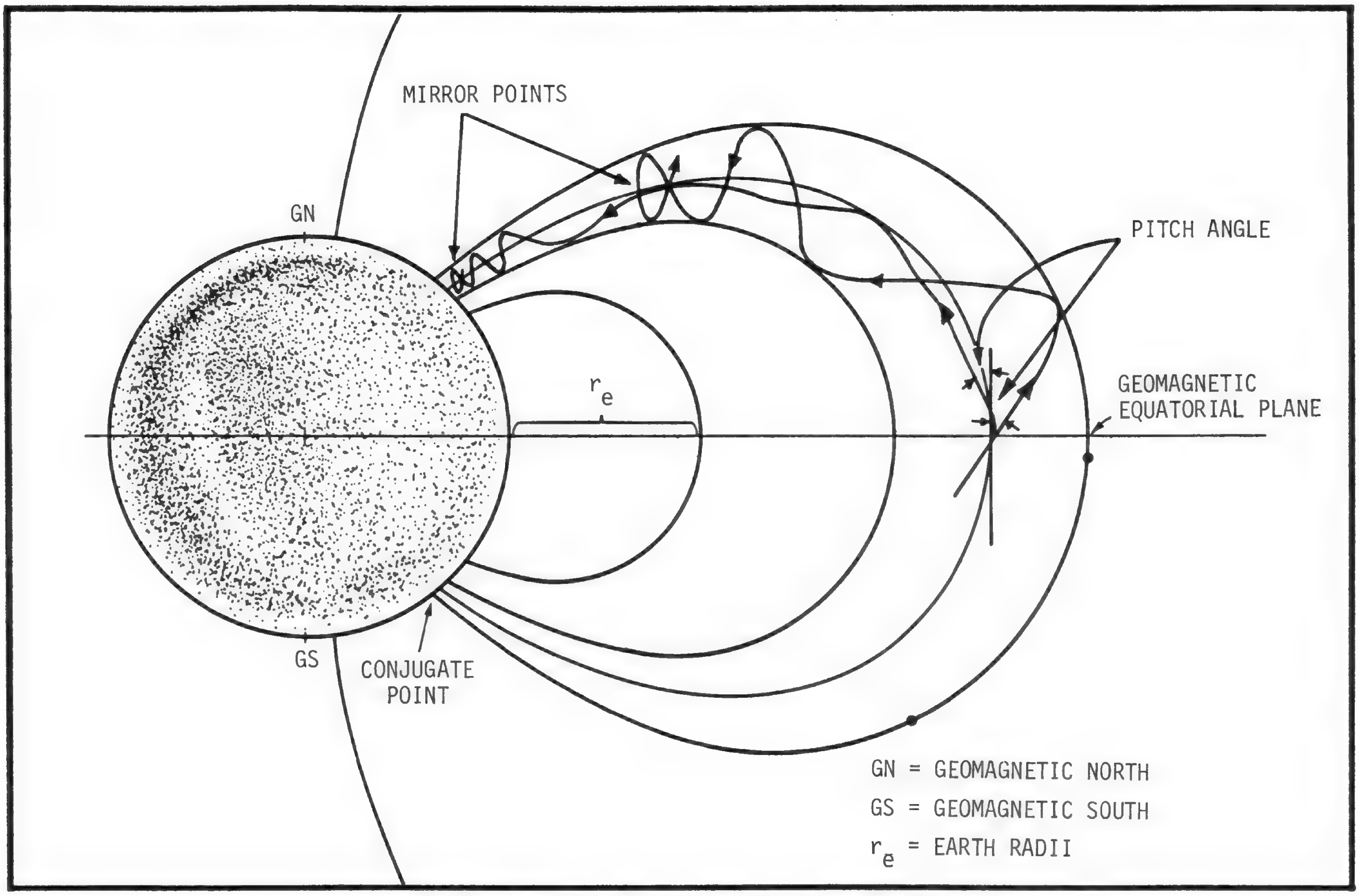


FIGURE 10-7. EARTH'S TRAPPED RADIATION DIAGRAM

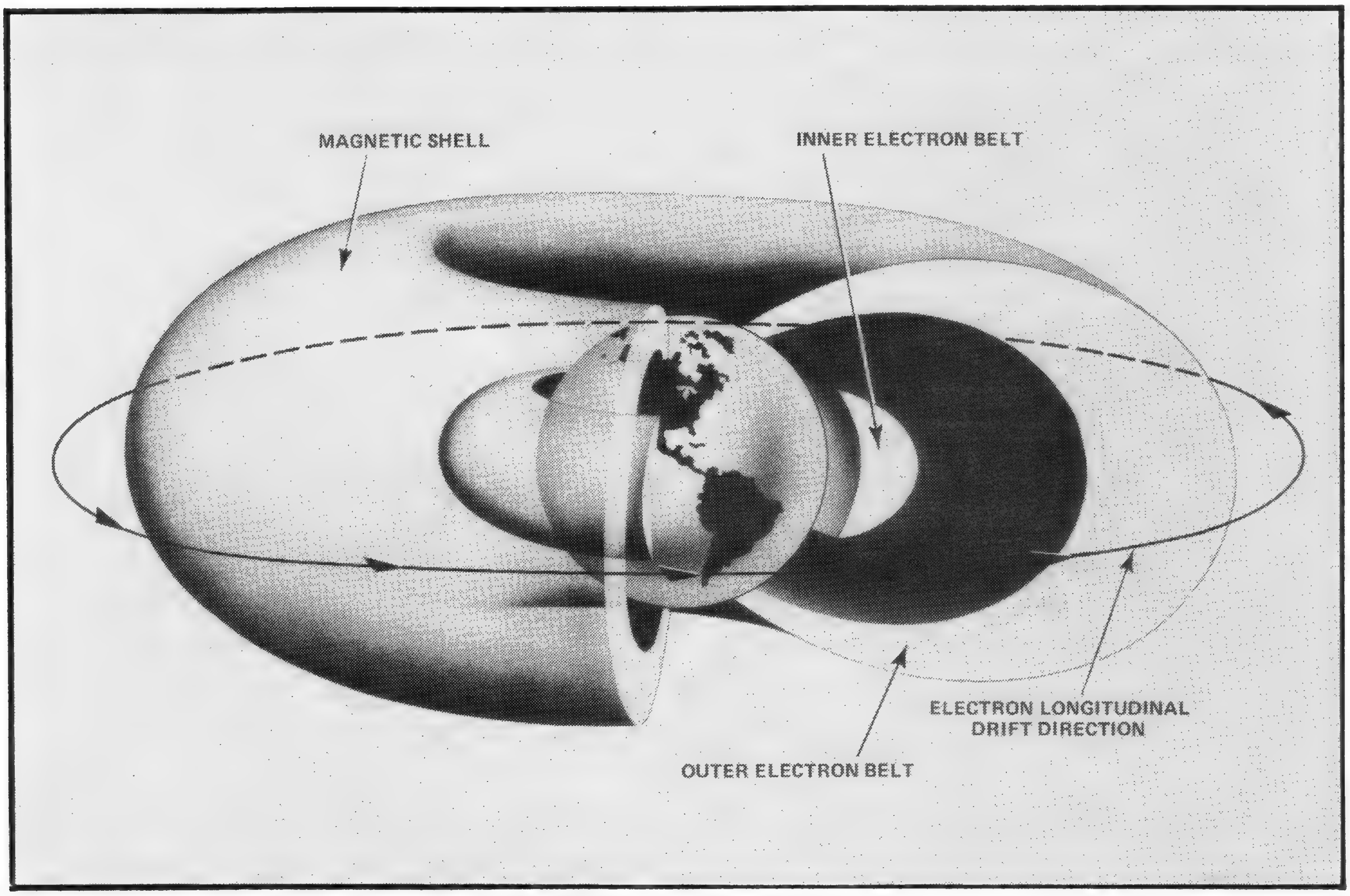


FIGURE 10-8. VAN ALLEN BELTS

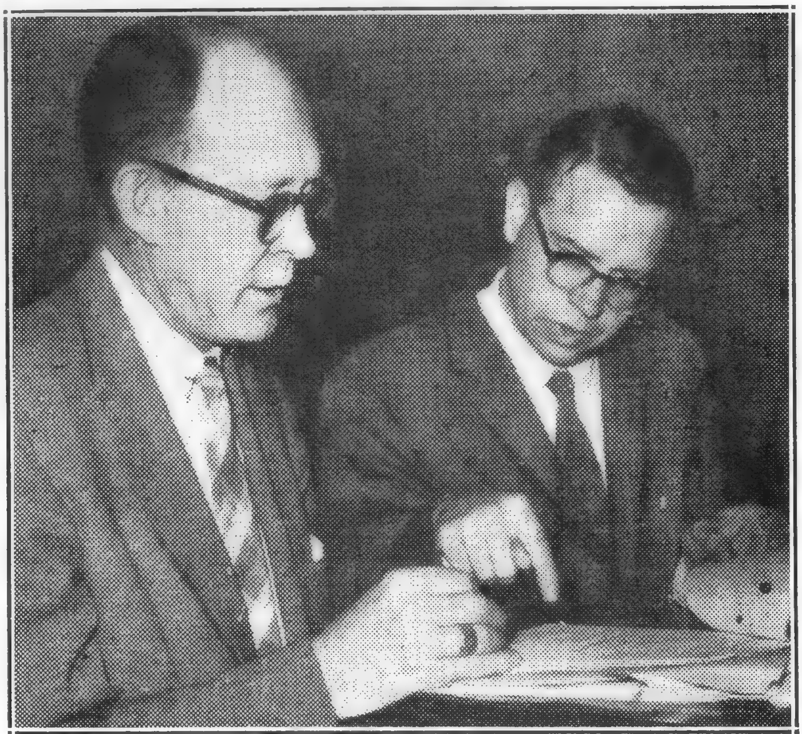
New York Daily News May 11, 1959

The Fateful Issue of Fallout—Rumor, Truth and Confusion

(Editor's Note: One of the most important—and most controversial issues—of our time is the problem of atomic fallout. Will it give your children cancer or will it injure the sensitive tissues of babies? Is it silently damaging the carriers of heredity so that thousands of people in future generations will be unnecessarily injured of killed? These life-and-death issues, the subject of Congressional hearings, are discussed and to some extent clarified in a series of two articles from THE NEWS' *Washington Bureau.)*

By MICHAEL O'NEILL

Washington, May 10.—The issue of atomic fallout, one of the most fateful of our time, has become such a colossal muddle that most Americans can't decide whether to be scared or blase—or, in frustration, just plain indifferent. It's gotten to the point where the confusion is almost as bad as the radiation. Scientists, politicians, diplomats and a miscellaneous assortment of ax-grinders are all sounding off in every direction.



(Associated Press foto)

Drs. Willard Libby (left) and Frank Shelton appear before subcommittee during extensive hearings on atomic fallout.

The supermarket of opinion provides both forecasts of eventual suicide for the human race and assurances that fallout is no more dangerous than a dental X-ray, or a ride in the country on a Sunday afternoon. And in the middle of it all, as usual, is the ordinary citizen who is uncertain about everything except that if anybody makes a mistake he'll probably be the loser.

In four days of hearings last week, a subcommittee of the Senate-House Atomic Energy Committee sought to bring some order out of the chaos. More than two dozen nationally known authorities—from the Atomic Energy Commission, the Public Health Service, and university laboratories—were summoned to report on the present state of our fallout knowledge.

STILL A THREAD OF AGREEMENT

As they probed the extraordinary complexities of the problem, as they argued over some questions and confessed their ignorance about many others, they tended to reinforce the public impression of confusion and controversy. But throughout their testimony there was still a tenuous thread of agreement on some fundamental issues. And even if an understanding of these does not clarify everything, it at least helps put the fallout threat in better perspective.

To begin with, the scientists on both sides of the dispute agree there is nothing good about fallout. On this there is no controversy. They believe that the silent, unseen rain of radioactivity from nuclear explosions is adding to the world's burden

FIGURE 10-23. FALLOUT--RUMOR, TRUTH AND CONFUSION

THE EVENING STAR
Washington, D. C., May 11, 1959

Key Fallout Problem Is Reported Solved

By RICHARD FRYLUND
Star Staff Writer

One of the great problems of the radioactive fallout hazard has been solved.

Witnesses before the Joint Congressional Committee on Atomic Energy reported yesterday that scientists now know the mechanism of fallout—how the radioactive material gets high into the air, how it circulates, how long it stays aloft, how it comes back to earth and where it falls.

Until yesterday this information has been a matter of public dispute by scientists and sometimes bitter, partisan debate in Congress and Federal agencies.

This leaves one more vast area of uncertainty, however, before the true hazard of radioactive fallout can be assessed. That area is the biological effect of fallout—its effect on people.

Five-Point Summary

To sum up, the new picture of fallout, now generally accepted by all the scientists involved, is this:

First the radioactive debris from atomic explosions equivalent to some 30 million tons of TNT is now in the stratosphere. This is considerably less than many previous estimates. The significance is that less remains to fall on us, but less future testing can be done without increasing the level of hazard.

Second, the material does not fall uniformly on the world's just and unjust. It is concentrated in the northern hemisphere in the latitudes which include the United States. This settles an old argument over uniformity.

Third, the dangerous material falls out rather quickly. A year ago scientists thought it took seven years for half of the material to fall out, seven years for half of the remainder, and so on. After yesterday, the accepted figure is two years half-residency for material blasted upward near the equator and one year for material sent up near the Arctic. Therefore, the far-north Soviet tests are the most dangerous.

Hits Middle Latitudes

Fourth, the material does not filter down evenly all over the world through the tropopause (the dividing line, about five miles high, between the stratosphere, where the material rests in the still, almost airless sky, and the troposphere, the turbulent lower area where the weather is). It comes through that barrier only at "breaks" which exist at about 40 degrees where rainstorms carry it on down to the surface of the earth.

This new concept accounts for the concentration belt which makes radioactivity in the United States, particularly the northern regions, high.

Fifth, there are seasonal variations in fallout. The spring is heaviest. We are now headed into the worst fallout spring since the first A-bomb.

Will Study Effects

Dr. Frank Shelton, technical director of the Armed Forces Special Weapons Project, who just finished the heart of the definitive mechanism survey, believes efforts of Government scientists can now be turned most profitably to a determination of how human beings, plants and animals are affected by the fallout.

After another year's double-check in the northern and southern hemisphere of the fallout mechanism, Dr. Shelton believes his own shop could stop operations.

The radiation subcommittee of the Atomic Energy Committee is holding a series of hearings under the chairmanship of Representative Holifield, Democrat of California, to bring fallout information up to date and to determine what can be taken out of the realm of controversy and what can be presented to the public as reasonably sure scientific fact.

Yesterday's findings were the result of a global survey of fallout. Measurements were taken in balloons and airplanes, in rain clouds, in lakes, wheat fields and on rooftops. Hundreds of scientists in the Defense Department, AEC, Weather Bureau and Public Health Service were involved.

Scientists Testify

The first witness, Dr. C. L. Dunham, chief of the biology and medicine division of the Atomic Energy Commission, summed up the fallout picture in a 127-page report that emphasized the need for more research on the physical hazard of radiation. Dr. Francis J. Weber, chief of the division of Radiological health of the Public Health Service, recommended that "we continue to measure and measure and that the research now under way be expanded."

Aspects of the fallout mechanism were then discussed by Mr. Joshua Holland, division of biology and medicine, AEC; Dr. Shelton; Dr Lester Machta, United States Weather Bureau; Dr. E. A. Martell, Cambridge Research Center, United States Air Force, and Dr. W. F. Libby, Atomic Energy Commissioner.

Before the current hearings, Congress—and the public—had not known how much potentially dangerous radioactive material was in the upper atmosphere, how fast it was falling on the food we eat or where the fallout was concentrated.

Saw Data Withheld

Committee members, particularly Mr. Holifield and Senator Anderson, Democrat of New Mexico, became convinced that the AEC and Pentagon were withholding information from the public on the danger of fallout.

Yesterday's "reveal all" testimony was not particularly comforting—it indicated the fallout danger is certainly no less than supposed—but it did indicate that the Federal agencies previously were holding out on the public more out of ignorance than a desire for secrecy.

FIGURE 10-24. KEY FALLOUT PROBLEM IS REPORTED SOLVED

The Evening Star June 22, 1959

World Would Survive Atom War, Expert Says

Congress Is Told Countries Not Attacked Would Suffer, But Still Could Go On

By RICHARD FRYKLUND

Star Staff Writer

The popular conception of a world population destroyed by fallout after a nuclear war, is mistaken, a congressional committee was told today.

Dr. Frank Shelton, technical director of the Defense Department's Atomic Support Agency, told a subcommittee of the Joint Committee on Atomic Energy that world-wide fallout would not threaten the survival of countries not attacked, even during a "large-scale" nuclear war.

The best-selling novel "On the Beach" is wrong, Dr. Shelton said, in picturing a deadly fallout cloud gradually encompassing the entire earth.

"Medium" War Postulated

The committee today opened a week-long series of hearings on the effects of a hypothetical war between the United States and Russia. The group envisions medium scale war in which the United States, Russia and some European countries are hit directly by large nuclear bombs.

Dr. Shelton said the radioactive strontium 90 in the bones of people around the world would rise only "slightly higher than the maximum permissible concentrations" set as a guide to radiation hazard. The added gynetic dose would be only the equivalent of the present natural radiation, he said.

Dr. Shelton concluded that other countries would survive handily even though they might have grounds to worry about an increase in cancer and defective children in future generations.

Death to All in 7 Miles

No person within seven miles of a large nuclear explosion would have more than a slim chance to survive, Dr. Shelton said.

The committee is assuming that Washington would be hit by two bombs, one of 8 megatons and the other of 10 megatons. A megaton is the equivalent in blast destruction of a million tons of TNT.

Dr. Shelton said that direct radiation from a 10-megaton bomb would kill everyone exposed to it within 2 miles of the blast. Even brick buildings would be destroyed in an area 7 miles from the explosion, crushing people who took shelter and leaving others exposed to fallout radiation and heat damage.

Persons within 25 miles of the explosion, Dr. Shelton said, would suffer second - degree burns on all exposed parts of their bodies. The bomb would make a 240-foot-deep crater, 2,500 feet in diameter.

Dr. Shelton said people downwind from the blast would be killed by fallout radiation in an area roughly 100 miles long and 17 miles wide.

Most wooden buildings would catch fire in an area 25 miles from the explosion.

Senator Anderson, Democrat of New Mexico, asked what these blast figures would mean in simple human terms. "What will happen to me, standing 10 miles from the Capitol downwind from the center of the explosion?" he asked.

Dr. Shelton said almost all wooden houses and most brick buildings in his area would be destroyed during the first minute after the explosion. The fallout effect would not come for a half hour, he said, but it would be strong enough when it arrived to give an unsheltered person a deadly dose of radiation in minutes.

Attack Date Assumed

The hearings, according to Subcommittee Chairman Holifield, Democrat of California, are designed to clear up the "considerable confusion" in the public mind about the effects of nuclear war. The hearings will assume that 224 cities, military installations and Atomic Energy Commission centers, will be hit by 1,446 megatons of large nuclear bombs. The attack takes place at 7 a.m. Washington time, in mid-October. The weather is assured to be that which actually existed on October 17, 1958.

Eugene Quindlen of the Office of Defense Mobilization said casualties and destruction will be based on an assumption that no cities are evacuated, that no extensive air raid shelter systems exist, but that people have enough warning to hide in buildings.

Chairman Holifield read a message to the subcommittee from Lt. Gen. James E. Gavin, former head of research and development for the Army, saying that the conditions of the atomic war assumed by the committee are "entirely realistic."

FIGURE 10-28. WORLD WOULD SURVIVE ATOM WAR, EXPERT SAYS

was not criticized publicly by anybody. The only criticism which was made of that decision was that the cutback on defense against bombers did not go far enough. Yet some years ago, in 1956, when General Partridge testified on the state of our defenses, he made it very clear they were not adequate to defend our country and would not be adequate in the near future; his testimony did not depend in any sharp way on large estimates of the number of Russian long-range bombers; their TU-4's, and Badgers, and small numbers of Bears and Bisons, being sufficient. They did not have to have 500 or 1,000 Bears and Bisons to do the job."

"The reason why there is not criticism of the decision to cut back on air defense is that people believe we must deter all-out war, we must be able to fight limited wars, we must have arms control and that is all. They do not really believe we have to be able to fight a general war, usually not because they are certain one cannot happen, but because they do not believe that anyone can survive a general war. They do not believe that there is a significant difference between victory, stalemate, and defeat."

"The testimony before this Committee was, I think, in that sense very salutatory. As far as I know, Dr. Frank Shelton was the first Government official to make the flat statement that the next war would not destroy all human beings, worldwide."

"This may strike those who know, in this committee room, as a rather silly view (that the next war would end all civilization), that is held by maybe a few uneducated laymen. It is not like that. Very distinguished scientists hold that view. And I mean very distinguished. And a couple of years ago they would have been willing to argue with you numerically that they were right. . . . There was a recent debate in the New Leader magazine between Bertrand Russell and Sidney Hook on, 'Was it legitimate, or was it not, to risk killing all human beings in the world in the attempt to resist Communism?' That was a serious debate. Nobody raised the question, that the debate was about a hypothetical subject which was not at issue. One does not kill all human beings, or even a majority of them, in a war. . . ."

". . . Some of the Europeans raised the question: Would American aid be on the way if the Russians seriously challenged us? Would we (the Americans) live up to our alliance obligations? . . ."

". . . Now let me ask every man in this room to put himself in the place of the President of the United States. Assume that the Russians have done something very horrible, say dropped a bomb on London, on Rome, Paris, Berlin, the worst thing you can imagine, but have not touched the United States. By some mechanism the President cannot react immediately. He has 24 hours to think over what he will do; at which point he has to decide whether to press the button and punish the Russians, but in turn accept the retaliatory attack upon the United States. . . . I do not know how the President would act . . . We cannot say whether the Soviet retaliatory threat would be effective at exactly 5 or 30 or 100 million dead (Americans). . . . many Europeans will say, 'At no price will the Americans retaliate . . . .' On the other hand, the typical American will say, 'We cannot be bluffed or blackmailed at any price.'"

"It is important, in other words, to differentiate very sharply between what I have called Type One Deterrence, which is trying to deter a direct attack on the United States, and what I have called Type Two Deterrence, which is trying to deter an extremely provocative action. . . ."

"As long as we think of a thermonuclear war as a sort of end of history, we may not feel acutely uncomfortable about placing all of our reliance either on deterrence or on measures to alleviate tension, as this seems to be all we can do. . . . (However, we should actually feel very uncomfortable, because that isn't the way the world really is)."

Whereupon, at 12:30 p.m., the hearing was recessed . . . .

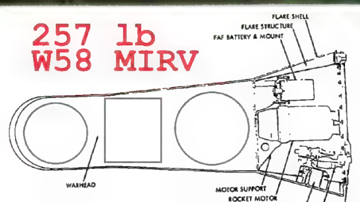
THE LAST YEAR WAS THE WORST YEAR

For the Eisenhower Administration, 1960 was a bad year, and also the last year of a full two-term Presidency. As bad years go, it was comparable to the Reagan Administration's year of "selling arms to Iran for hostages." Both Presidents got caught, publicly, doing what they thought was in the best interests of the United States, but the lower level management of the operations "screwed up." In Eisenhower's case,

FIGURE 11-5. TRUCKEE EVENT AT CHRISTMAS ISLAND

210 kt TRUCKEE was the key W58 (15.6" diameter, 40.3" long) MIRV warhead nuclear proof test for Polaris A-3 SLBM, which contained a bus of three W58's (10kt boosted KINGLET primary with TUBA U235 oralloy spherical secondary stage). The last W58 was retired in 1982.

257 lb
W58 MIRV



Honolulu Star-Bulletin

KGMB THE NEWS STATION CBS IN THE PACIFIC Radio 590, Channels 9, 3

Vol. 51, No. 189 HONOLULU, HAWAII, MONDAY, JULY 9, 1962 ★★★★ HOME EDITION 10¢

N-Blast Produces Colorful Display

Color photos by Terry Luke show how last night's hydrogen bomb explosion looked fr... ...al Bank Building is the bomb center. Cen-Punchbowl. The first photo was exposed at exactly 11 p.m., the moment of ignition. ... photo was taken about 11.01 p.m. with the sky dominated by greenish colors. The light was so intense that the sky appears blue as in daylight. The light spot in the sky ... ight hand photo was made at about 11.05 p.m. just before the color faded.

Spectacular Test Shot Lights All Islands

... Johnston in Auckland, New Zealand.

Sightings were ... from Samoa ...

... but today scientists are beginning the task of collecting and analyzing data ... around the world to determine its effects.

... An Atomic Energy Commission official at Pearl Harbor this morning de... ...the explosion ... a scientific experiment."

He said he doubted ... would be made known until "sometime in the future."

"They will be studying this for weeks and months to come," the spokesman said.

The spokesman added that the height of the detonation would continue to be kept secret. So would the yield of the nuclear device.

There has been no confirmation that a second test will be conducted from Johnston Island. Three and possibly four were scheduled.

Precisely at H-Hour as a short-waved countdown reached zero, the bomb flashed with instantaneous daytime brilliance in Honolulu's southwest sky.

It was perhaps 15 degrees above the horizon, indicating an altitude of several hundred miles. The bomb center registered a pinpoint of light on camera films.

The first flash was followed by the appearance of

Turn to Page 1-A, Column 1

★ ★ ★

Shock Wave May Have Put Out Lights

The City-County Street ...

More Stories on Pages 2-A, 2-B, 24-B

The Johnston nuclear blast flooded the beach at the Hawaiian Village in Waikiki with an eerie light last night.—Star-Bulletin Photo by Amos Chun.

★ ★ ★

Blackouts Brief In Communications

The thermonuclear blast over Johnston Island last night didn't affect communications as much as expected but the Federal Aviation Agency said it experienced occasional blackouts for about two hours after the 11 p.m. blast.

But since then communication has been normal, an F.A.A. spokesman said.

Australia and Japan also reported similar brief interruptions soon after the blast.

The F.A.A. official in Honolulu said the "occasional short outages (signal going out) affected point-to-point communication in all directions."

He estimated the duration at 20 to 30 minutes, but the interruptions disappeared after about two hours and communication has been normal since.

He said communication between Honolulu Airport and aircraft in the air was perfect at all times.

Some Honolulu radio stations were washed out by interference but returned to the air immediately.

The Japanese Overseas Telephone and Telegraph Company rep... pacific telephone c... with Honolulu, O... and Buenos Aires, Ar... were knocked out right after the explosion but service was restored a short time later, Associated Press ...

In Sydney, Australia, an

Turn to Page 2-B, Column 8

Most Going Into Orbit

Little Fallout Seen From Test

WASHINGTON, July 9 (UPI)—Atomic experts expect ... any radioactive fallout from the nuclear explo... in space over Johnston Island.

Some of the bomb debris, perhaps as much as half, may be hurled free of the earth's gravitational field and wind up wandering through space in long orbits around the sun. A part of what is left is expected to go into orbit around the earth.

The remainder may well be held aloft, far above the weather regio... of the atmosphere so long and be... ...that it will be comparatively har... the time ...

There is no do... ...ground ...

A Defense D... ...estimated that half of the radioactive debris ... a megaton bomb exploded at an altitude of 100

Turn to Page 1-A, Column 6

DIRECTORY

FIGURE 11-21. STARFISH EVENT -- HONOLULU NEWSPAPER

FIGURE 11-28. STARFISH EVENT FROM CHRISTMAS ISLAND

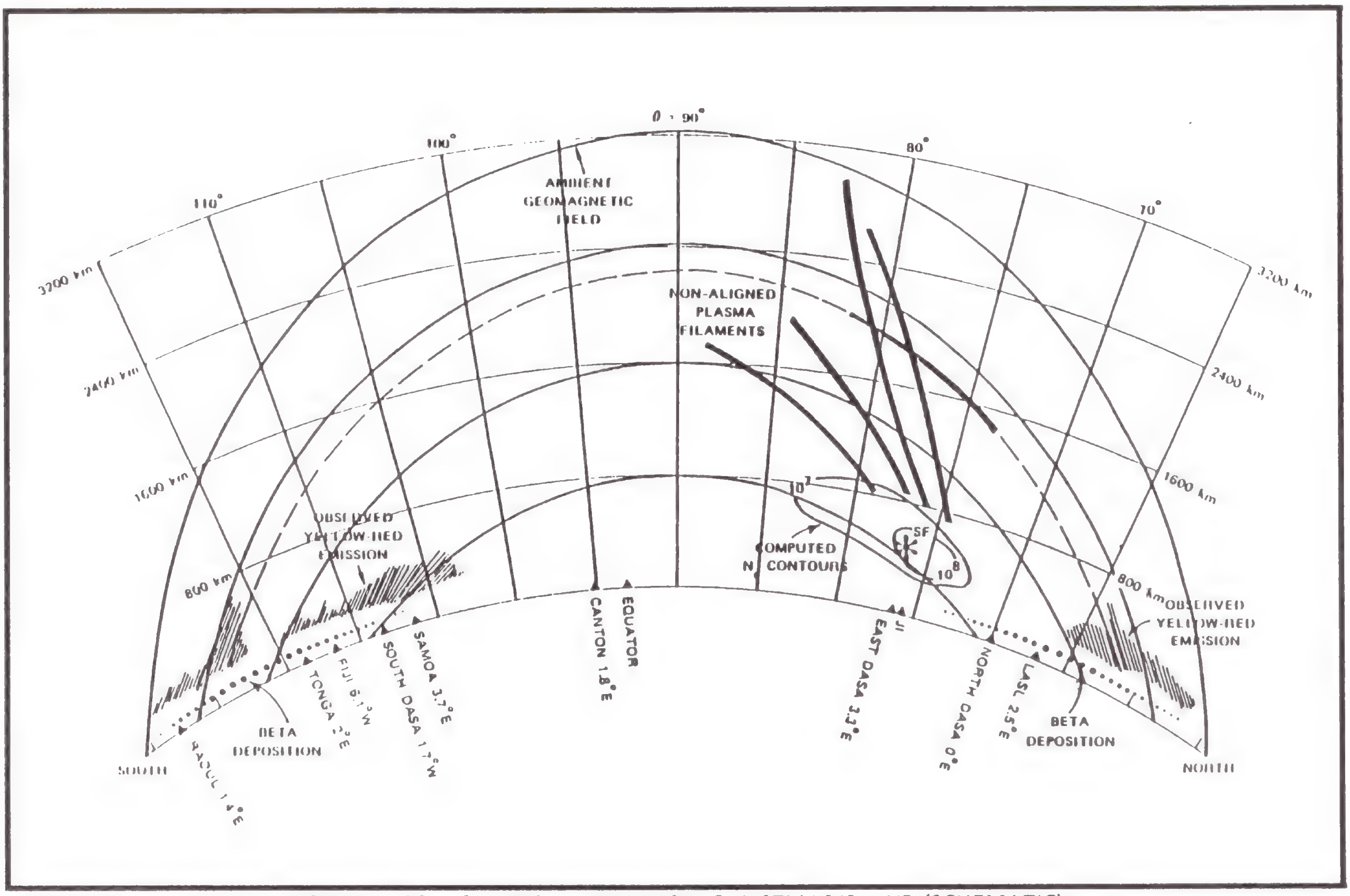


FIGURE 11-29. STARFISH EVENT FROM CHRISTMAS ISLAND (SCHEMATIC)

NUCLEAR SURVIVAL IN THE UK - AIDE MEMOIRE

D/DAT/13/33/9 Code 71136

Aim

1. To give guidelines for the preparation of survival measures in the event of a nuclear attack on the UK.

THE NUCLEAR EXPLOSION

Blast, Heat and Initial Radiation

2. The destructive effect of nuclear weapons is due mainly to blast or shock. A nuclear explosion also emits:

a. Light and heat, capable of causing skin burn, eye dazzle, and of starting fires at considerable distances.

b. Highly penetrating, invisible rays which can kill or cause skin injury.

Fallout

3. Fallout will only occur when the fire ball touches the ground although immediately after the explosion there will be a period of relative safety prior to the arrival of fallout.

4. The radiation from fallout is dangerous and can only be detected by special instruments for measuring dose rates and total doses.

SURVIVAL PLANNING

Shelter

5. The first priority is to select a suitable building for the fallout shelters. Factors affecting selection are:

a. The building should be of strong construction.

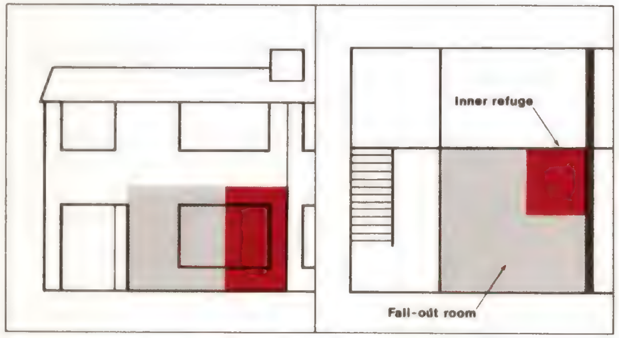
b. Do not select a single storey building, unless unavoidable.

c. Avoid buildings on high or exposed ground.

d. If possible choose a building with a cellar.

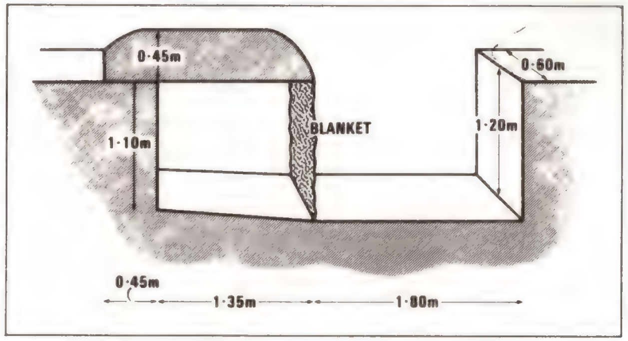
6. In addition to buildings, consideration should be given to the use of railway tunnels, caves or mine workings. In the case of the last two the threat of flooding should be assessed.

7. ***The Fallout Room.*** Having chosen a building, select a room furthest from the outside walls and the roof, or one which has the smallest amount of outside wall. If possible use a cellar or basement, otherwise a room on the ground floor. Windows, doors and chimneys should be blocked and the floors above thickened to give added protection against the penetration of radiation. Thick dense materials are the best; bricks, concrete or building blocks, timber, boxes or bags of sand or earth and even furniture might well be used. External combustible surfaces and windows should be whitewashed against the heat flash and fire points set up round the building. If the room selected is above ground level dig slit trenches for initial survival, prior to fallout.



8. ***The Inner Refuge.*** Within the fallout room build an inner refuge which will provide even greater protection during the period that heavy radiation is present (up to 2 days at least). This may be constructed on an ad hoc basis. For example: a lean-to made of doors, a staircase or a table reinforced with bags or boxes filled with earth.

9. ***Shelter.*** If no suitable buildings can be found then adequate protection can be provided by slit trenches with overhead cover. If time is available larger shelters as described in the Army Survival in the UK Pamphlet, can be constructed.



Stores

10. It is expected that the radiation hazard will require people to remain under cover for up to 14 days. Therefore provision should be made for sufficient stores for this period.

a. ***Drinking Water.*** A minimum of 2 pints per man per day — a total of $3\frac{1}{2}$ gallons.

b. ***Food.*** Ideally compo, but any tinned non perishable food will suffice. Remember cooking facilities may be limited.

c. ***Communications.***
(1) Field radio.
(2) Field telephone.
(3) A portable battery operated radio suitable for national broadcast reception.
Spare batteries should be taken.

d. ***Lighting.*** If possible use a generator if not tilly lamps, veh battery and headlights, torches or candles. Remember to have plenty of spare fuel and batteries.

e. ***Sanitation.*** Use an elsan or bucket lined with a plastic bag. When full, dump in a large bin outside the fallout room. Keep a good stock of toilet paper and strong disinfectant.

f. ***Radiac Instruments.*** Dosimeters and radiac survey meters as issued.

g. ***Miscellaneous.***
(1) Cooker or stove (NOT HEXAMINE if in a confined and poorly ventilated room.
(2) Sandbags or plastic bags, for rubbish.
(3) First Aid Kit.
(4) Rope and a knife.
(5) Pick, shovel and axe.
(6) Fire extinguisher.

CHECK LIST BEFORE ATTACK	Tick when completed
1. Ensure that everyone understands the warning signals and action to be taken. 2. Select the fall-out shelter. 3. Block doors, windows and chimney and reinforce the walls and roof/ceiling. 4. Whitewash windows. Set up fire points. 5. Select and prepare inner refuge. 6. Dig slit trenches. 7. Take necessary action to protect equipment left outside the shelter. 8. ***Stores.*** a. Water $3\frac{1}{2}$ gallons per man. b. Food for 14 days. c. Field radio, telephone — spare. d. Transistor radio — spare batteries. e. Lighting equipment. f. Sanitation arrangements and paper and disinfectant. g. Radiac Instruments. h. Cooker, sandbags, first aid kit, rope, pick, shovel, axe, tools and fire extinguisher. j. Individual kit — respirator, warm clothing, sleeping bag and books, cards, etc.	
Attack Warning 9. Put vehicles under cover. 10. Turn off gas and extinguish fires and stoves. 11. Shut windows. 12. Take cover. 13. Switch off radio and disconnect battery and antenna.	
After Attack 14. **DO NOT SMOKE** — Check for gas leaks. 15. Check for fires. 16. Make essential repairs if necessary. 17. Give First Aid. 18. Check survival kit. 19. Attempt to re-establish communications and listen to national broadcasts. 20. Be ready to return to the fall-out shelter. 21. Wipe dust off clothing and skin before re-entering shelter.	

NUCLEAR WEAPONS AND PREVENTING WAR

1 Nuclear weapons have transformed our view of war. Though they have been used only twice, half a lifetime ago, the terrible experience of Hiroshima and Nagasaki must be always in our minds. But the scale of that horror makes it all the more necessary that revulsion be partnered by clear thinking. If it is not, we may find ourselves having to learn again, in the appalling school of practical experience, that abhorrence of war is no substitute for realistic plans to prevent it.

2 There can be opposing views about whether the world would be safer and more peaceful if nuclear weapons had never been invented. But that is academic; they cannot be disinvented. Our task now is to devise a system for living in peace and freedom while ensuring that nuclear weapons are never used, either to destroy or to blackmail.

3 Nuclear weapons are the dominant aspect of modern war potential. But they are not the only aspect we should fear. Save at the very end, World War II was fought entirely with what are comfortably called "conventional" weapons, yet during its six years something like fifty million people were killed. Since 1945 "conventional" war has killed up to ten million more. The "conventional" weapons with which any East-West war would be fought today are much more powerful than those of 1939-1945; and chemical weapons are far more lethal than when they were last used widely, over sixty years ago. Action about nuclear weapons which left, or seemed to leave, the field free for non-nuclear war could be calamitous.

4 Moreover, whatever promises might have been given in peace, no alliance possessing nuclear weapons could be counted on to accept major non-nuclear defeat and conquest without using its nuclear power. Non-nuclear war between East and West is by far the likeliest road to nuclear war.

5 We must therefore seek to prevent any war, not just nuclear war, between East and West And the part nuclear weapons have to play in this is made all the greater by the facts of military power. The combination of geography and totalitarian direction of resources gives the Soviet Union a massive preponderance in Europe. The Western democracies have enough economic strength to match the East, if their peoples so chose. But the cost to social and other aims would be huge, and the resulting forces would still not make our nuclear weapons unnecessary. No Western non-nuclear effort could keep us safe against one-sided Eastern nuclear power.

6 An enormous literature has sprung up around the concepts of deterrence in the nuclear age. Much of it seems remote and abstruse, and its apparent detachment often sounds repugnant. But though the idea of deterrence is old and looks simple, making it work effectively in today's world needs clear thought on complex issues. The central aim is to influence the calculations of anyone who might consider aggression; to influence them decisively; and, crucially, to influence them before aggression is ever launched. It is not certain that any East-West conflict would rise to all-out nuclear war: escalation is a matter of human decision, not an inexorable scientific process. It is perfectly sensible–indeed essential–to make plans which could increase and exploit whatever chance there might be of ending war short of global catastrophe. But that chance will always be precarious, whether at the conventional or the nuclear level; amid the confusion, passions and irrationalities of war, escalation must always be a grave danger. The only safe course is outright prevention.

7 Planning deterrence means thinking through the possible reasoning of an adversary and the way in which alternative courses of action might appear to him in advance. It also means doing this in his terms, not in ours; and allowing for how he might think in future circumstances, not just in today's. In essence we seek to ensure that, whatever military aggression or political bullying a future Soviet leader might contemplate, he could not foresee any likely situation in which the West would be left with no realistic alternative to surrender

8 Failure to recognise this complicated but crucial fact about deterrence–that it rests, like a chess master's strategy, on blocking off in advance a variety of possible moves in an opponent's mind–underlies many of the criticisms made of Western security policy. To make provision for having practical courses of action available in nuclear war (or for reducing its devastation in some degree by modest civil defence precautions) is not in the least to have a "war-fighting strategy", or to plan for nuclear war as something expected or probable. It is, on the contrary, a necessary path to deterrence, to rendering nuclear was as improbable as we humanly can. The further evolution in 1980 of United States nuclear planning illustrates the point. The reason for having available a wider range of "non-city" target options was not in order to fight a limited nuclear war–the United States repeatedly stressed that it did not believe in any such notion–but to help ensure that even if an adversary believed in limited nuclear war (as Soviet writings sometimes suggest) he could not expect actually to win one.

9 The United Kingdom helped to develop NATO's deterrent strategy, and we are involved in its nuclear aspects at three main levels. First, we endorse it fully as helping to guarantee our security, and we share in the protection it gives all Alliance members. Second, we cooperate directly, like several other members, in the United States power which is the main component of the nuclear armoury, by making bases available and providing certain delivery systems to carry United States warheads. Third, we commit to the Alliance nuclear forces of various kinds–stategic and theatre–under our independent control. The details of all this are matters of debate, which the Government welcomes. But the debate should recognise that positions which seek to wash British hands of nuclear affairs, while continuing (as NATO membership implies) to welcome United States nuclear protection through the Alliance, offer neither moral merit nor greater safety. Whether we like the fact or not, and whether nuclear weapons are based here or not, our country's size and location make it militarily crucial to NATO and so an inevitable target in war. A "nuclear-free" Britain would mean a weaker NATO, weaker deterrence, and more risk of war; and if war started we would if anything be more likely, not less, to come under nuclear attack.

10 The East-West peace has held so far for thirty-five years. This is a striking achievement, with political systems so sharply opposed and points of friction potentially so many. No-one can ever prove that deterrence centred on nuclear weapons has played a key part; but common sense suggests that it must have done. Deterrence can continue to hold, with growing stability as the two sides deepen their understanding of how the system must work and how dangers must be avoided. Not since the Soviet gamble over Cuba in 1962 have we come anywhere near the brink. It is entirely possible, if we plan wisely, to go on enjoying both peace and freedom–that is, to avoid the bogus choice of "Red or dead".

11 To recognise the success of deterrence is not to accept it as the last word in ensuring freedom from war. Any readiness by one nation to use nuclear weapons against another, even in self-defence, is terrible. No-one–especially from within the ethical traditions of the free world, with their special respect for individual life–can acquiesce comfortably in it as the basis of international peace for the rest of time. We have to seek unremittingly, through arms control and otherwise, for better ways of ordering the world. But the search may be a very long one. No safer system than deterrence is yet in view, and impatience would be a catastrophic guide in the search. To tear down the present structure, imperfect but effective, before a better one is firmly within our grasp would be an immensely dangerous and irresponsible act.

Prepared by Ministry of Defence Public Relations. Designed and Produced by Main Titles Ltd. Printed by E. G. Bond Ltd.

HOME OFFICE

Police Manual of Home Defence

Anyone finding this document is requested to hand it in at a Police Station

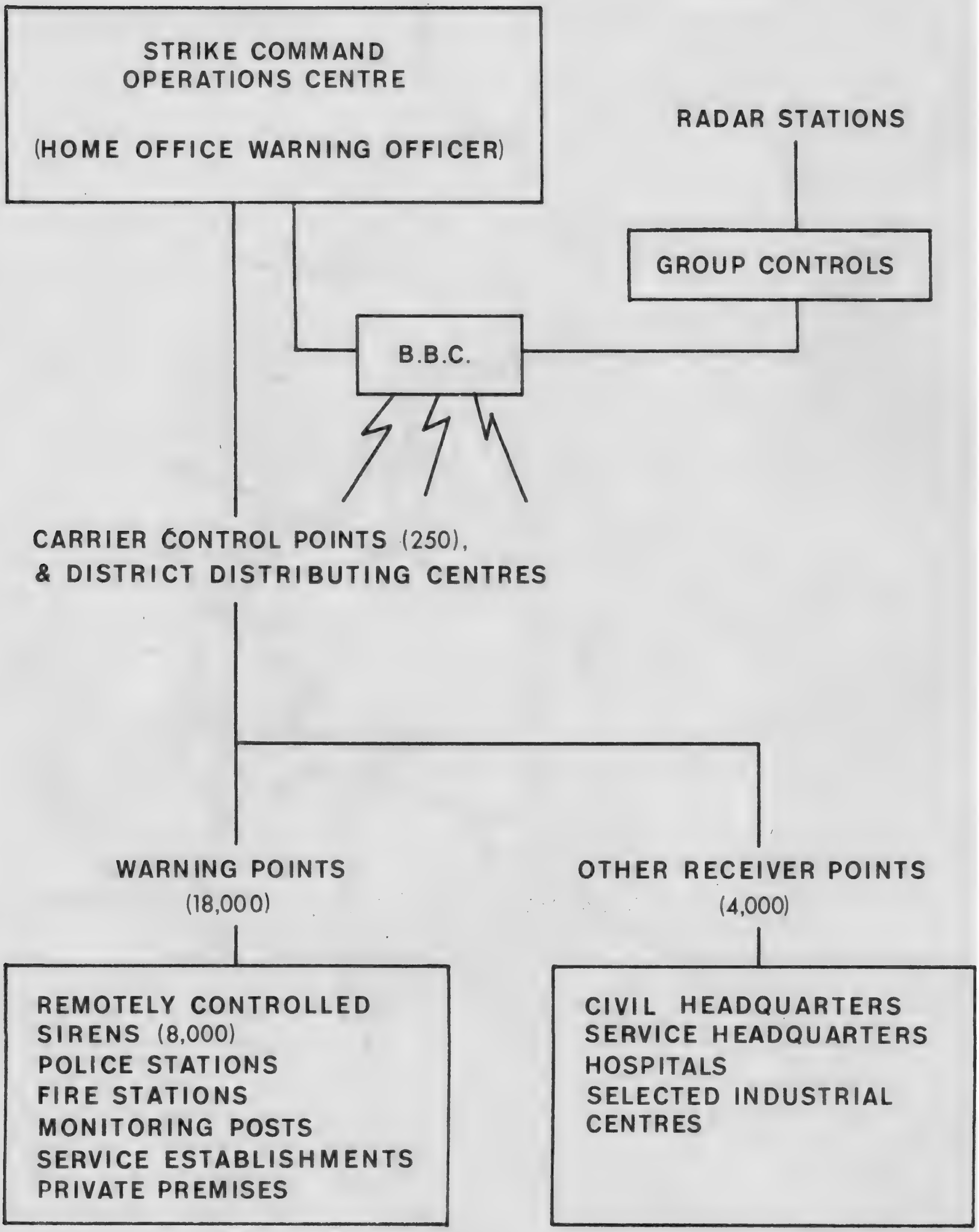
This manual should not be shown to anybody outside the Police Service

Restricted

London Her Majesty's Stationery Office

Appendix C

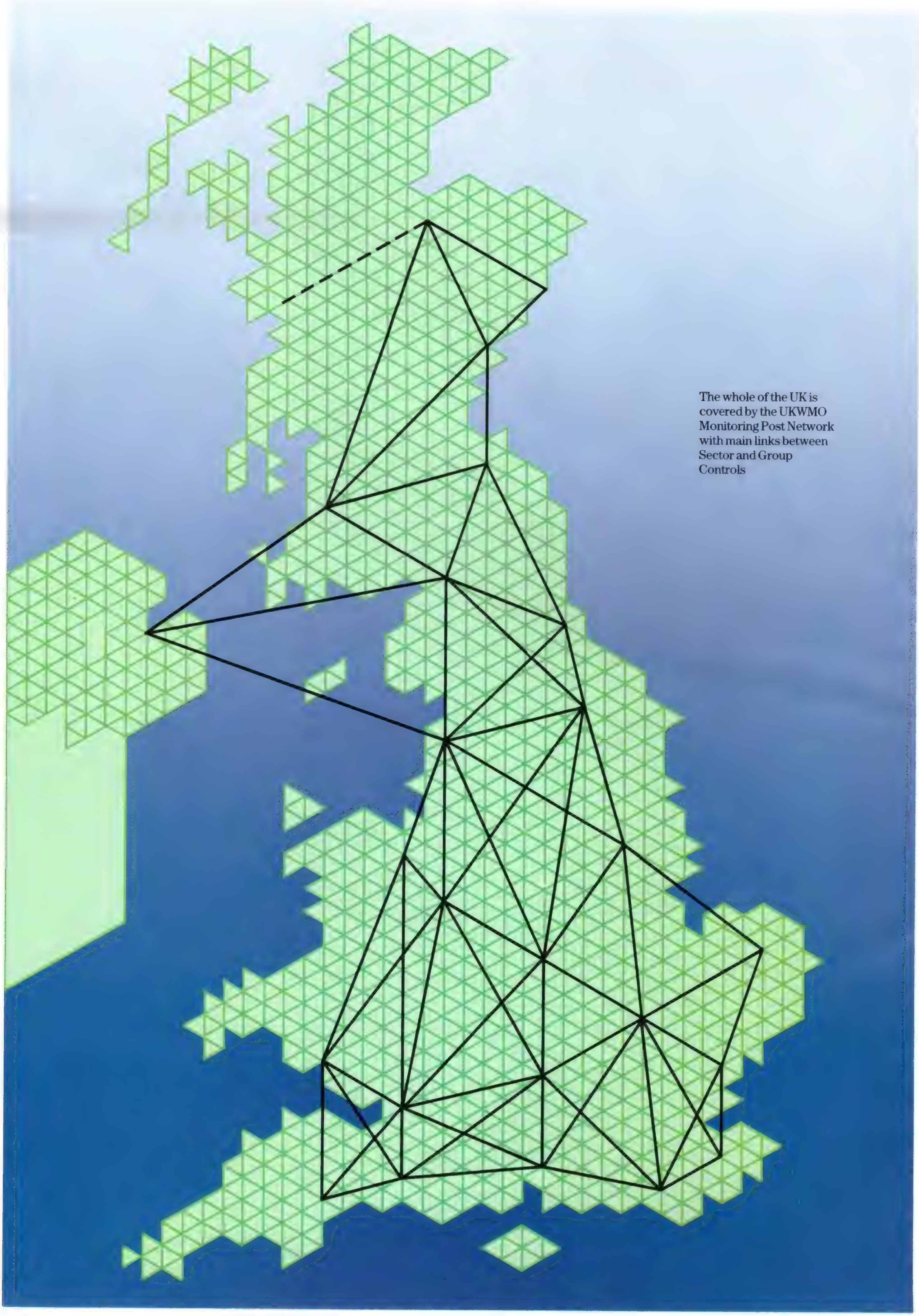
UKWMO system for issuing attack warnings



UKWMO

UNITED KINGDOM WARNING AND MONITORING ORGANISATION

Prepared for the Home Office by the Central Office of Information, 1985.
Printed in the UK for HMSO. Dd8832902 HOME J20443NE



The whole of the UK is covered by the UKWMO Monitoring Post Network with main links between Sector and Group Controls

PROTECTING BY WARNING

The United Kingdom is vulnerable to air attack and successive Governments, in their periodic reviews of the nation's defences, have given high priority to the maintenance of an effective air attack warning system covering the entire country. Such a system exists today, capable of giving timely warning of air attack whether by manned aircraft carrying conventional high-explosive bombs or by ballistic missiles with nuclear warheads. It is designed to be able to react swiftly to evidence of impending attack and to pass warning messages simultaneously to the civil population, to regional government HQs, local authority emergency centres and home defence forces.

It makes no sense, in this context, to talk of a warning of only a few minutes: while in certain circumstances, a very short warning might be all that is possible to give, in many other circumstances it is likely that a much longer warning could be given.

Warning could certainly save countless lives and this does not simply apply to warnings of air attack. If nuclear weapons were to be used against this country or anywhere in Europe, radioactive fallout could constitute a major hazard and warnings of its approach would need to be passed to those in its path.

As with warnings of air attack, so with warnings of the approach of fallout, a system covering the whole of the United Kingdom is already in existence — and has been for almost 30 years — under the control of the United Kingdom Warning and Monitoring Organisation (UKWMO).

UKWMO comes under the direct control of the Home Office. Although in peacetime it is run by a small full-time staff, during a national emergency it can be brought into full operation in a matter of hours. At peak strength, it is manned by many thousands of personnel, the vast majority of whom are volunteers recruited by the Home Departments and the Royal Observer Corps (ROC), who train and exercise regularly for their vital tasks in the event of war.

To be effective, this system relies on good communications. Considerable expenditure has been devoted over recent years to ensuring that UKWMO telecommunications equipment is up-to-date, reliable and flexible, not only within the United Kingdom but also so that information on air attack and details of nuclear bursts and fallout can be exchanged with neighbouring countries.

A warning system can only really be effective if those for whom it is intended are able to recognise the warning signals and know what action they are required to take. This is being incorporated in revised Government publications on civil defence preparations for issue to the public.

This booklet describes just how the warning and monitoring systems in the United Kingdom can be an effective life-saving measure in the event of war in Europe.

THE ROLE OF UKWMO

The five main functions of UKWMO are:

1 Warning of air attack — conventional and nuclear.
2 Confirming any nuclear strike.
3 Warning of the approach of radioactive fallout.
4 Supplying government headquarters and home defence forces in the UK and neighbouring countries with details of nuclear bursts and with a scientific assessment of the path and intensity of fallout.
5 Providing a post-attack meteorological service.

Effective warning of air attack and of radioactive fallout is of vital importance. It is often claimed that UKWMO will have fulfilled its essential role in effectively carrying out its warning function.

The task of monitoring fallout, calling for more resources of men and equipment, is another important service which would be carried out in support of Government measures to ensure public survival in areas affected by radiation.

1 The Operations Room at Fylingdales

WARNING AGAINST AIR ATTACK

Information on an impending air attack on this country would come from a number of sources, including the North American Air Defence System (NORAD) and the NATO European Air Defence Ground Environment System (NADGE) which includes the radars at our own RAF Sector Operations Centres (SOC) and early warning aircraft. In case of missile attack, warning would come from the Ballistic Missile Early Warning System (BMEWS) station at RAF Fylingdales, on the Yorkshire coast, backed up by further information from other stations of the system in Alaska and Greenland.

All these reports would be assessed by Home Office staff stationed at the United Kingdom Regional Air Operations Centre (UK RAOC). It would be for them to decide, in consultation with the air defence staff, whether to set the warning network in action. Turning a key in a special electronics box at UK RAOC simultaneously alerts 250 points — the Carrier Control Points (CCPs) — located in major police stations throughout the United Kingdom. By pressing a switch on the special communications equipment at each CCP, the police can activate powered sirens at strategic locations in urban parts of their warning area. In all, there are some 7,000 power-operated sirens installed throughout the country.

These are backed up by a network of some 11,000 other warning points in rural areas, located mostly at police, fire and coastguard stations, government and service establishments, hospitals, industrial centres, and monitoring posts manned by the Royal Observer Corps. Certain warning points are also to be found in shops, pubs and private homes, in areas where other suitable locations would not otherwise exist.

2 Ballistic missile threat display at Fylingdales

3 The Carrier Control Point receives and issues warnings of impending air attacks and the approach of fallout

Each CCP is linked to the warning points in its area of responsibility by means of a unidirectional carrier line broadcast system, which superimposes signals upon the existing local British Telecom telephone cable network without interfering with normal traffic carried on that network. A warning message can be broadcast over this system and heard by the warning point operator on a receiver unit, which resembles a small loudspeaker.

Upon receiving a warning of an air attack from the CCP over this system, a warning point operator would sound the alarm by hand-siren. At the same time, warnings would be broadcast on TV sound and radio. Altogether, the vast majority of the population would be alerted in sufficient time to take action to protect themselves against the danger.

A simple but effective warning code has been devised as an integral part of the UKWMO system (see page 12). It covers warnings both against air attack and radioactive fallout, and gives a subsequent 'All Clear' signal. Public service broadcasts would explain the different warning sounds to the public. The code can be easily understood by the public and conveys a sense of great urgency.

Power-operated sirens are located in urban areas. In rural parts of the country hand-sirens sound the alarm

WARNING AGAINST FALLOUT

Special procedures have been devised to provide effective warning of fallout, report nuclear bursts and, in the longer term, enable a scientific assessment of the paths and intensities of fallout to be made. These procedures are contained within a three-tiered, nation-wide structure which absorbs most of the personnel on the strength of UKWMO. At field level is a network of monitoring posts manned by members of the Royal Observer Corps. These are under the control of the second tier, known as Group Controls. In turn, Group Controls report developments in their areas to Sector Controls which, among other duties, are responsible for exchanging information with neighbouring countries.

As far as the general public is concerned, the key feature of this structure is the Group Control, for it is at this level that many basic decisions would be taken — and the intensity and likely behaviour of radioactive fallout assessed. It is here, also, that warnings of fallout would originate.

Altogether, there are 870 monitoring posts up and down the country. Each is responsible for sending information to one of the 25 Group Controls. In turn, there are five Sector Controls, four in England and one in Scotland, each with five Group Controls reporting to it. One of these, Western Sector Control, is also responsible for Northern Ireland.

Neighbouring Group Controls are linked by telegraph, telephone and radio, with computer-controlled message-switching facilities. Each Sector Control is co-located with one of its Group Controls — for example, near Lincoln, in the case of Midland Sector Control, and near Dundee, in the case of Caledonian Sector Control.

Apart from the lack of windows, there is nothing very conspicuous about the buildings housing Group and Sector Controls, but each has been purpose-built to withstand a certain amout of blast and to give protection against radioactive fallout. Each has its own stand-by services, including power, ventilation, sanitation, and food and water supplies.

Overall control of UKWMO is exercised by one of the five Sector Controls. Each Sector Control is capable of functioning as an independent unit and, with full communications between component parts, there is great flexibility in decision-making if parts of the Organisation were to be destroyed.

APPLYING METEOROLOGICAL INFORMATION

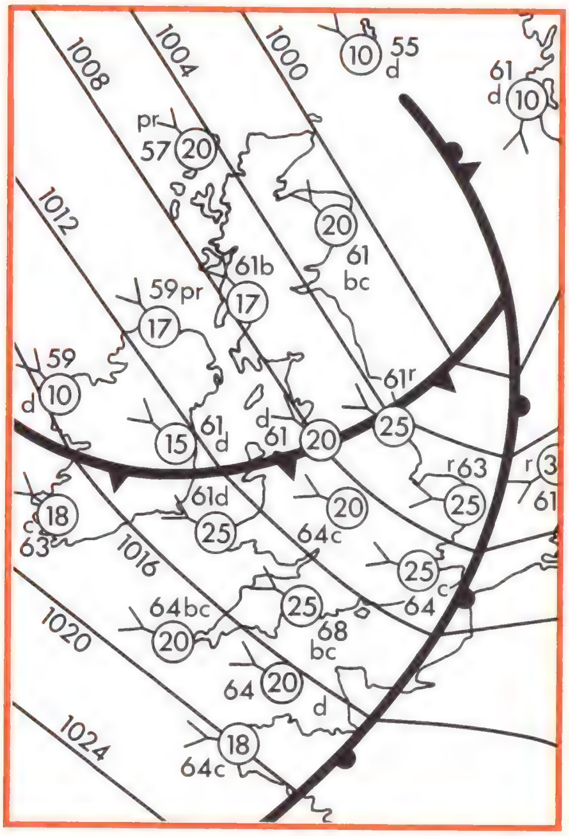
Meteorology would play a vital role in the work of UKWMO. The country's entire weather observation and forecasting services would be available to UKWMO and these facilities will be essential if the pattern of fallout over the British Isles and Western Europe is to be predicted and fallout warnings assessed.

At each Sector Control three specially trained meteorological forecasting officers would be available to interpret and make predictions from information fed in from the nerve-centre of the Meteorological Office — the Central Forecasting Office (CFO) at Bracknell in Berkshire. Yet even if this was destroyed by enemy action, each Sector Control could continue to draw on data provided through its direct links with the eight Radio Sonde or Upper Air Stations (UAS) in the country.

UKWMO would also contribute meteorological information through its network of 870 monitoring posts. Eighty-seven of these have been equipped with meteorological instruments, enabling ROC personnel at these posts to supply data to Group and Sector Controls on, for example, temperature, barometric pressure, wind direction and speed — all essential information for updating predictions of fallout behaviour.

In this way, UKWMO can provide a national meteorological service for both regional government HQs, local authority emergency centres and home defence forces.

Weather conditions determine the path of fallout



MONITORING POSTS

The frontline of fallout warning

Group Controls may represent the nerve-centres of UKWMO, but the monitoring posts make up the frontline — at least as far as nuclear activity is concerned.

In time of national emergency, these posts would be manned round the clock by personnel of the ROC: in peacetime, members of the Corps inspect their posts, check the equipment regularly and participate in training exercises. The ROC today is an integral part of UKWMO, though it still enjoys its distinct status and traditions which go back over some 60 years. It has a distinguished record as an aircraft reporting organisation throughout the period of the Second World War and for some time afterwards, before becoming the field force of the UKWMO.

Typical of the chain of monitoring posts, sited to cover the whole of the United Kingdom, is one only a few miles from a major city. It lies less than 200 yards from a main road, but it could easily go unnoticed. Above ground, the only signs of anything unusual are two objects, one a blue plastic dome and the other a large white canister. The first is the ionisation chamber of the fixed survey meter for measuring radiation levels. The other encases four pin-hole cameras so arranged that a nuclear burst in any direction from the post would record a mark indicating the bearing and elevation of the burst: it is called a 'ground zero indicator'. There is also an instrument known as a 'bomb power indicator' which records the blast-peak overpressure of an explosion. Some 20 feet below ground is a concrete chamber measuring about 7 x 16 feet x 7 feet in height, which is reached by a ladder running down a concrete shaft. As well as being linked to its Carrier Control Point for warning purposes, the post has a loud-speaking telephone link with its Group Control.

It would be the task of each monitoring post to report nuclear burst details to Group Control, beginning with the reading of blast-peak overpressure. This information would be followed up as soon as possible with details of the elevation, bearing and 'spot size' of the burst, recorded by the ground zero indicator.

The fixed survey meter above each post records the intensity of radioactive fallout. A post would report the arrival of fallout to its Group Control and thereafter would monitor the intensity of radioactivity, reporting the readings to the Group Control at regular intervals.

As one would expect, monitoring posts have been designed to withstand a certain amount of blast and give protection against fallout. As in the case of Group and Sector Controls, they have their own source of power, ventilation equipment, sanitation facilities and supplies of food and water.

UKWMO IN ACTION...

MONITORING POST...

1 Monitoring post observers at work

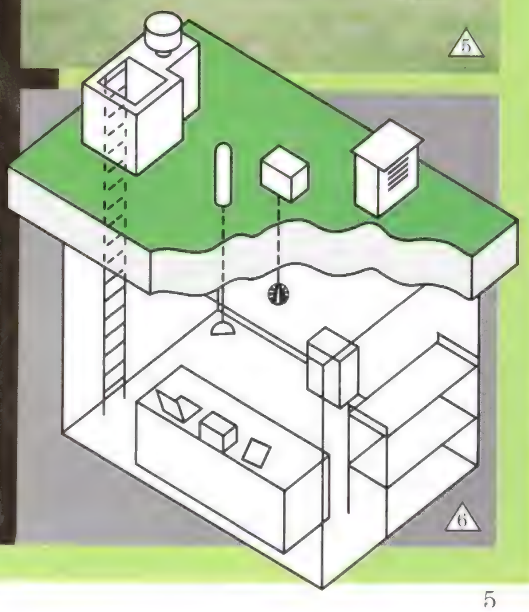
2 Loading a ground zero indicator which will show the direction and height of a bomb burst

3 Taking surface wind measurements

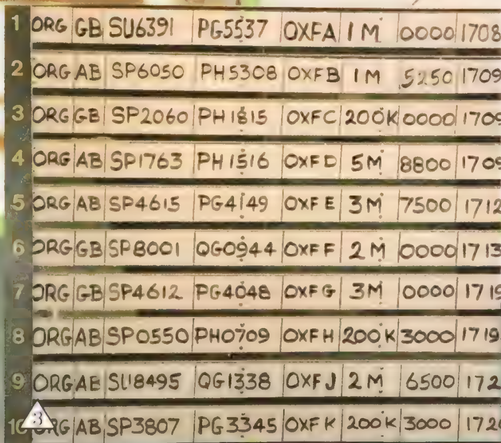
4 Most posts in rural areas are also Warning Points (see page 3)

5 A monitoring post above ground

6 A diagram of a monitoring post



GROUP CONTROL ...



1 Monitoring post information plotted

2 Triangulation team in a Group Control pinpoints a bomb burst

3 Nuclear burst data

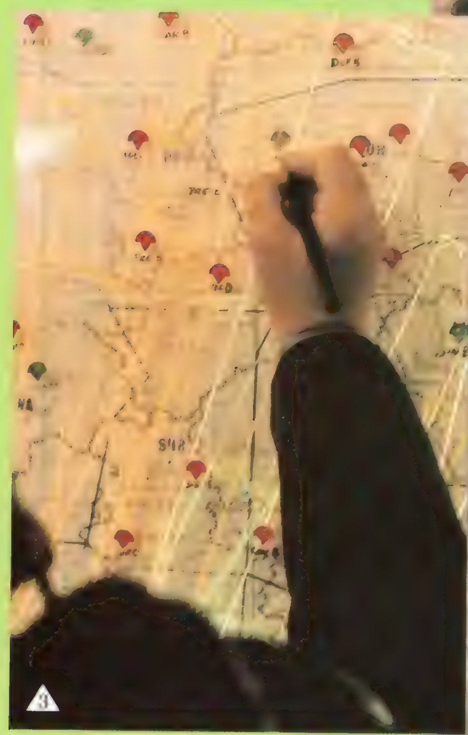
4 Monitoring post information displayed

5 Information for transmission through the computer controlled message switch

6 Information fed to the main displays

7 Monitoring post supervisor at work

SECTOR CONTROL ...



1 The Sector Operations Room

2 Assessing the radiological situation

3 Maintaining a national picture of bomb bursts and the threat they pose

4 Defining the area covered by fallout from each bomb burst

GROUP CONTROLS

The 25 Group Controls may be said to combine the functions of a post office with those of a data processing centre. Their main job is to evaluate reports of nuclear activity sent in by the monitoring posts. From these reports they would predict how fallout is likely to develop and issue warnings to the public on its approach. A second key job is to pass on findings and conclusions to other authorities, such as Sector Controls, regional government HQs, local authority emergency centres and home defence forces.

To do this, a typical Group Control would require about 50 trained personnel including some 40 ROC members and a team of warning officers, some of whom are scientists. It is these warning officers who make the decisions on whom to alert and when warnings should be issued.

Suppose, for example, a nuclear bomb were to explode in the Thames Estuary. Data on the burst would be sent in from various monitoring posts in the vicinity to Group Control at Maidstone. Here, using triangulation techniques, it would be determined whether it was an air or ground burst — the latter produces fallout. Its power and position would also be established.

A number of selected Group Controls have been equipped with electronic instrumentation called AWDREY — an acronym for Atomic Weapon Detection Recognition and Estimation of Yield — to register and confirm a nuclear explosion. Information from this equipment can also be used in the triangulation process.

1 & 2 AWDREY equipment on a Group Control

3 Typical operational control above ground

4 AWDREY Display Unit

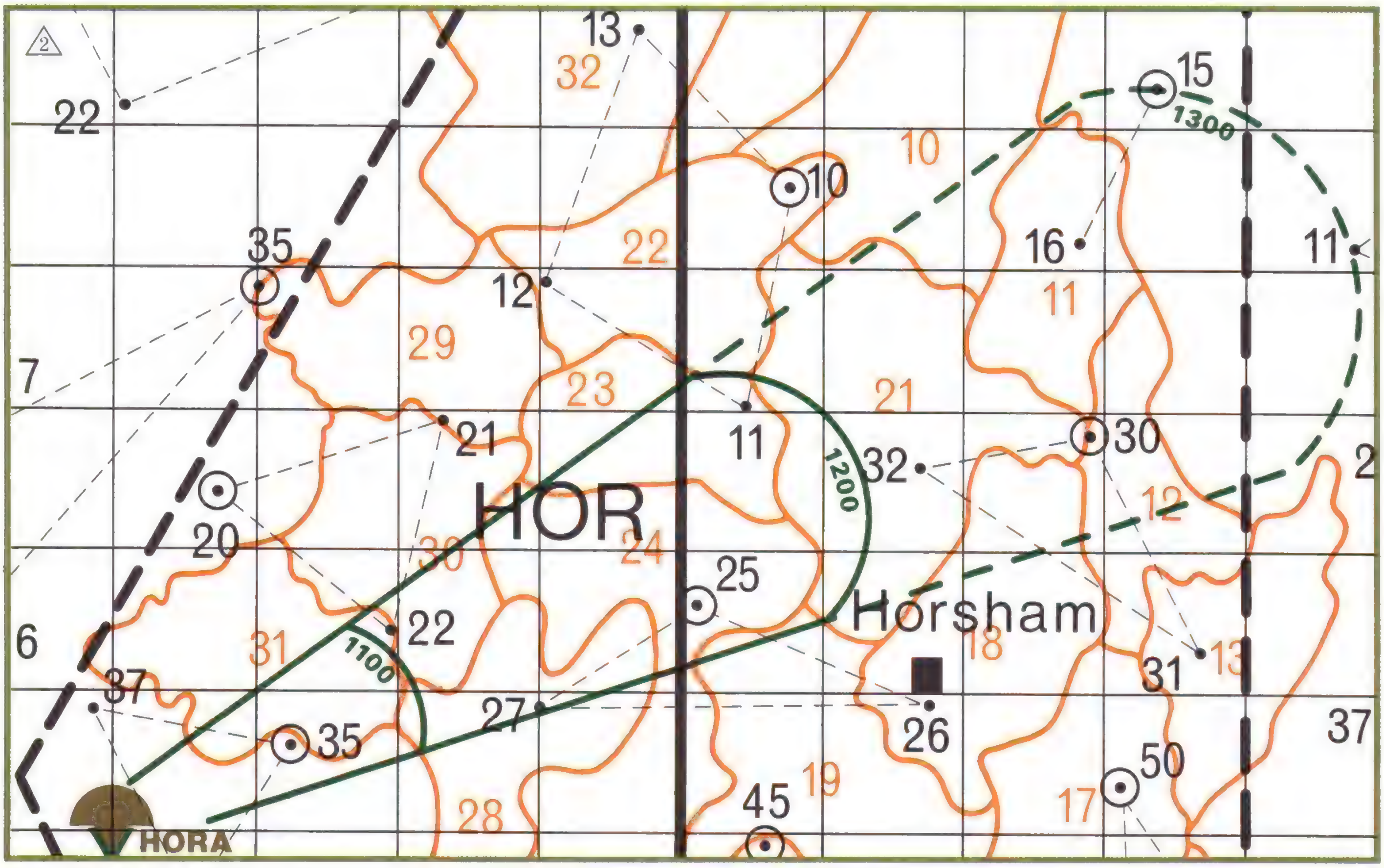
ASSESSMENT OF FALLOUT WARNINGS

Once the triangulation process has been completed at the Group Control, fallout warning assessments are made. These are based on two kinds of prediction. The first indicates the outer limit of the area within which fallout would be contained during the first hour or two after a nuclear burst. It is based on the information relating to the burst computed by the triangulation process, and also on meteorological forecasts compiled at the Sector Control, in particular the forecasts of speeds and directions of winds up to 100,000 feet.

The fallout warning procedure is based on a pattern of warning districts: there are 750 in the United Kingdom, each with an area of about 100 square miles. The warning would originate with a message from a Group Control to Carrier Control Points, from which the warning would be relayed to the various warning points over the carrier line broadcast system. Each of these is equipped with a maroon for sounding the fallout warning and with a radiac survey meter for measuring the level of radioactivity. If a warning point should find itself isolated, the operator would fire his maroon when fallout was detected on the meter.

Subsequently the warning team would work on a second type of fallout prediction: one derived from actual times of fallout arrival, as observed from ground readings, supported by further meteorological forecasts. Predictions of this type would give a more accurate picture of the probable path of fallout up to some three hours ahead of its arrival. Meanwhile, ROC personnel in the monitoring posts would be transmitting details of radiation dose-rate readings at regular intervals. These readings would be plotted on graphs, making it possible both to map areas of high radiation risk and to predict later arrivals of fallout. This information, together with the earlier fallout predictions, would also be passed to regional government HQs, local authority emergency centres, home defence forces and, through Sector Controls, to neighbouring countries.

1 Firing maroons provides an audible warning of the approach of fallout



2 Display charting predicted and actual path of fallout

SECTOR CONTROLS

Each Sector Control co-ordinates the activities of the Group Controls under its responsibility and controls communications within its territory. Another key function is to offer high-level scientific advice and generally to ensure that UKWMO's operational responsibilities are being met.

It is also responsible for liaison with specific neighbouring countries, the Channel Islands and the Isle of Man. For example, Midland Sector liaises with Denmark, Germany and the Netherlands, while Metropolitan Sector liaises with France and Belgium. In the event of an emergency, specially trained British Liaison Officers resident in adjacent countries would report to Warning and Monitoring Headquarters, and Liaison Officers from adjacent countries would report to Sector Controls in the United Kingdom. These officers would be responsible for reporting to their respective countries information on air attacks and details of nuclear bursts when resultant fallout may affect them.

When fully operational, each Sector Control would need a staff of about 80 including sector scientific advisers whose job would be to advise on any unexpected developments.

FOR SURVIVAL IN CRISIS

UKWMO is maintained at a high state of readiness through the use of a comprehensive but simple, robust and flexible system. In the final analysis, even if the structure of the UKWMO were extensively damaged, there should still exist sufficient alternative means of issuing warning messages and serving the Government's emergency control network responsible for advising the public on survival under fallout.

UKWMO is only one of a number of services planned by the Government to go into action in time of national emergency — and each of these has a vital contribution to make. As far as the system described in these pages is concerned, experts have calculated that its contribution could amount to the saving of millions of lives — simply by warning enough people in time.

WARNING CODE

The following types of warning will be given:

RED:

Air Attack Warning:

given by siren (rising and falling note) and by BBC broadcast.

This means imminent danger of attack from the air.

BLACK:

Fallout Warning:

given by maroon, gong or whistle (three bangs or blasts in quick succession): reinforced by information messages broadcast by local BBC stations wherever possible.

This means imminent danger of fallout.

WHITE:

All Clear:

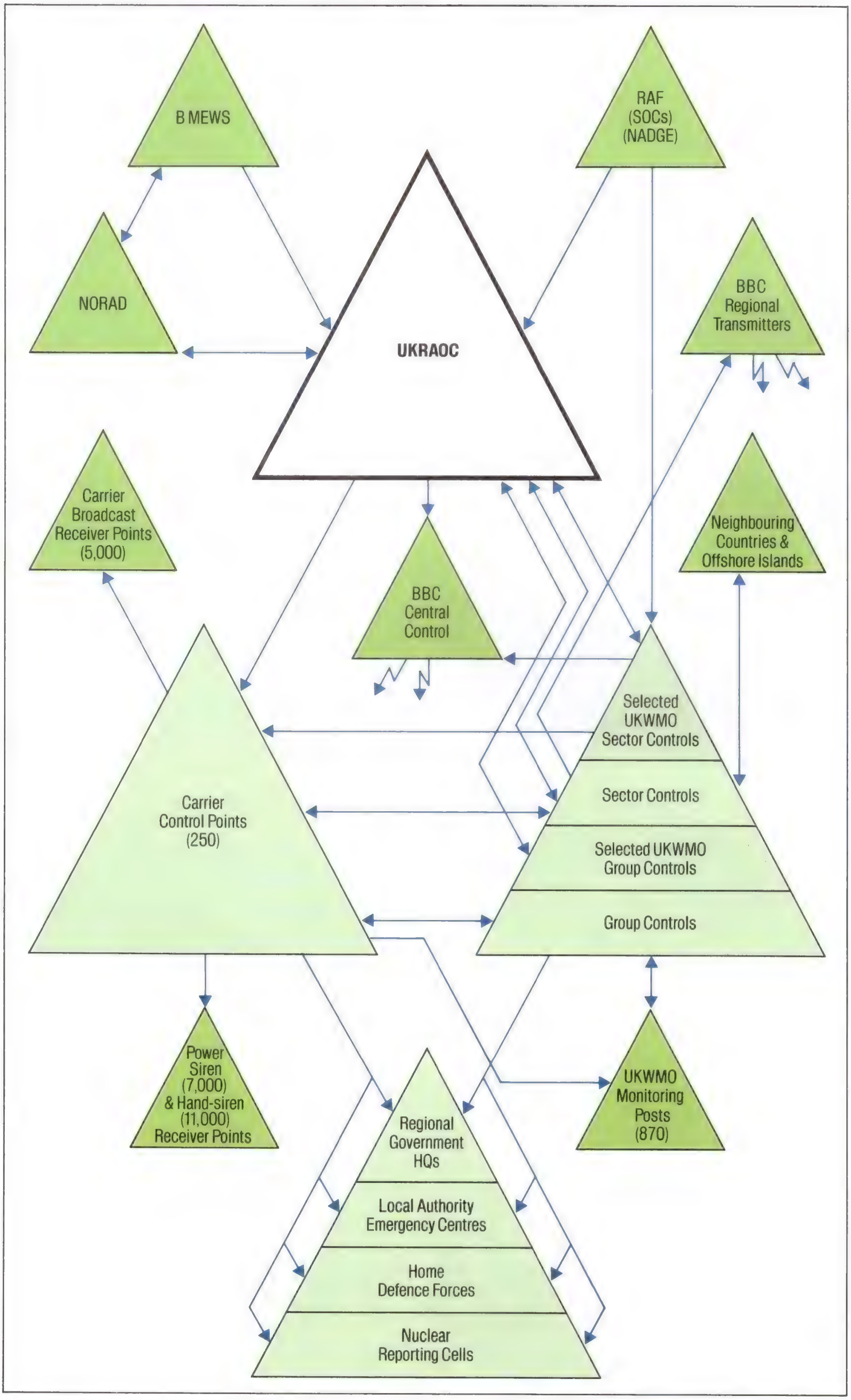
given by siren (steady note) and by BBC broadcast.

This means no further danger from air attack or fallout.

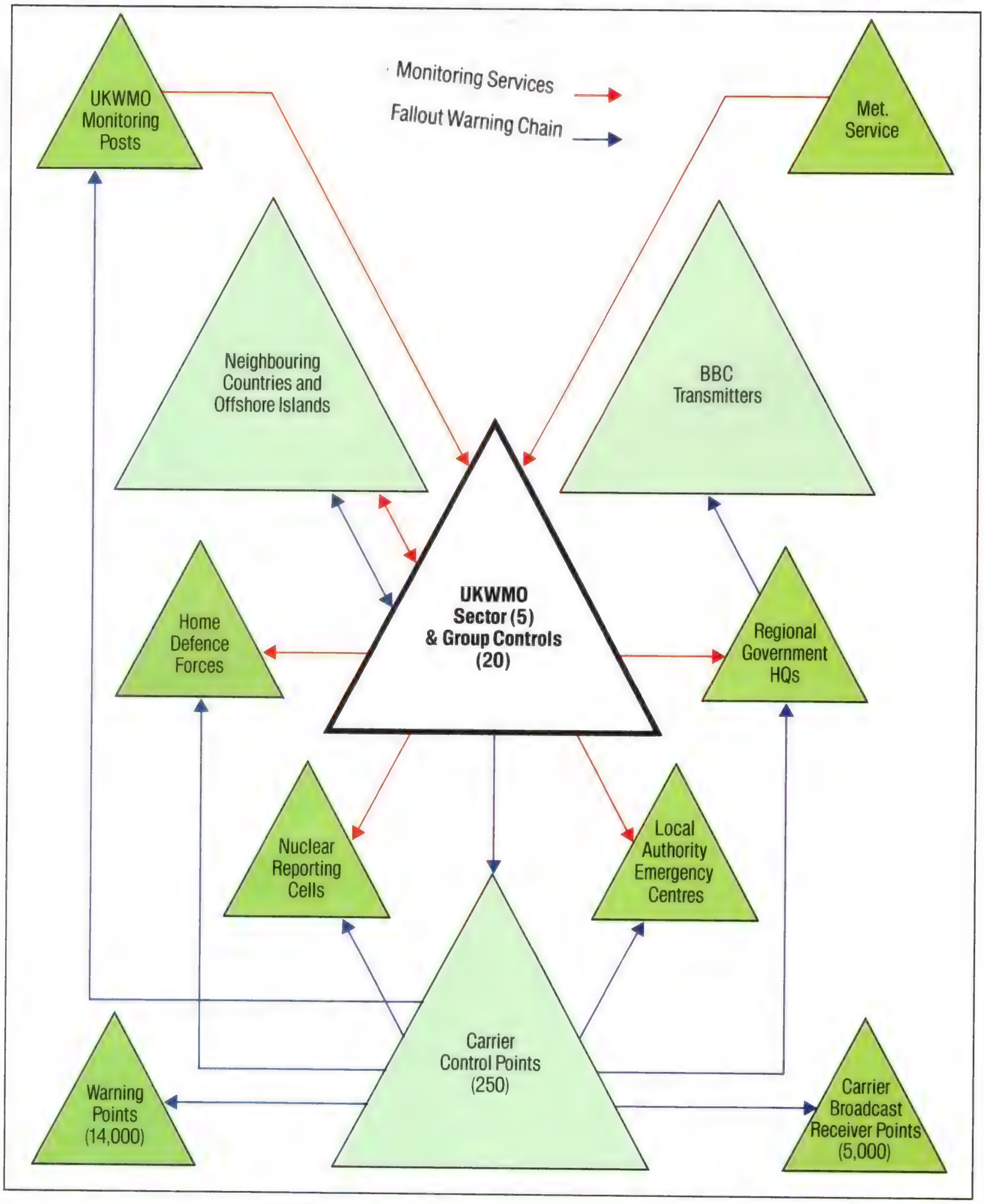
1 Sector Scientific Advisers consider a problem

2 Liaison Officers from neighbouring countries in a Sector Control

UKWMO AIR ATTACK WARNING SYSTEM



UKWMO FALLOUT WARNING AND MONITORING SYSTEMS



Further information regarding UKWMO – including the Royal Observer Corps – can be obtained from:

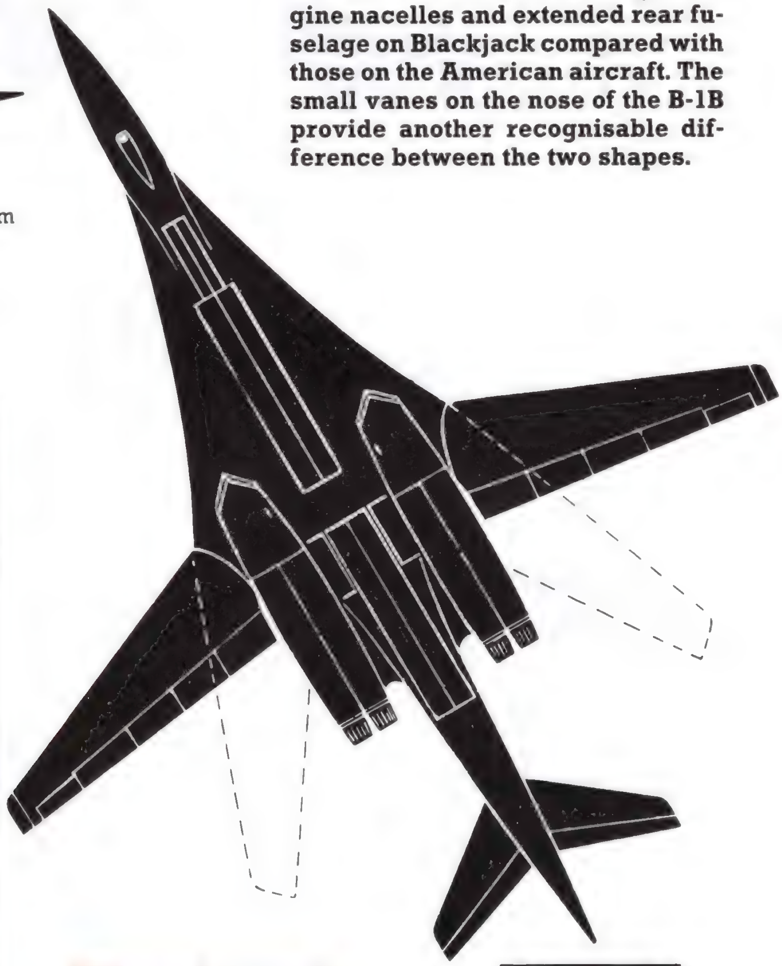
In case of difficulty, contact HQ UKWMO at:
HQ UKWMO
James Wolfe Road
Cowley
OXFORD
OX4 2PT

Dimensions:
B-1B length 44.8m (147ft); wing span (15° sweep) 41.7m (136ft 9in)

B-1B

Plan views of the two aircraft to scale. Noticeable are the longer engine nacelles and extended rear fuselage on Blackjack compared with those on the American aircraft. The small vanes on the nose of the B-1B provide another recognisable difference between the two shapes.

Dimensions:
Blackjack length 54m (177ft); wing span (20° sweep) 55.5m (182ft)



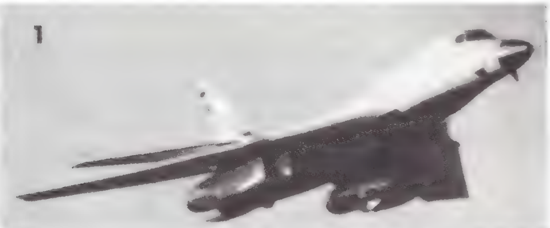
Blackjack

A VISUAL comparison

A
VISUAL comparison

B-1B/BLACKJACK Lesson instructions

To learn to recognise the difference between the B-1B and Blackjack, test yourself on the small views below. You should compile a list of numbers 1 to 18, then study the foregoing comparison lesson and the two key views above. Consider each view and write down your answer against the appropriate number. Your answers can be checked against the solutions printed inverted at the foot of the page.

1


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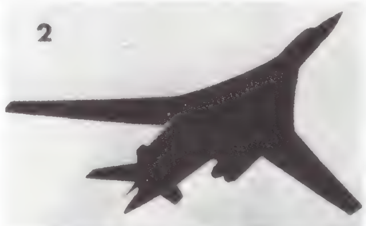

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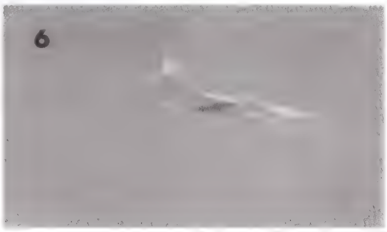

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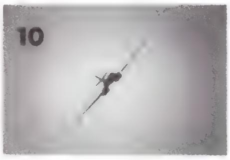

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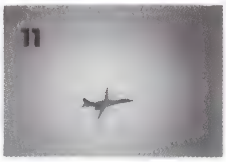

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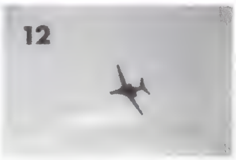

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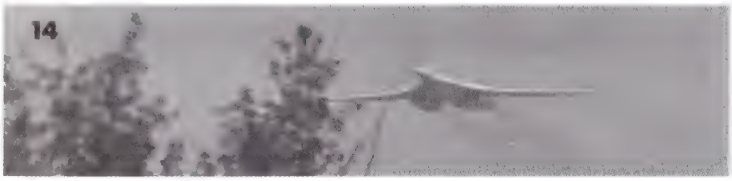


15


16


Solutions:
The American B-1B is shown in views No 1, 3, 9, 10, 11, 12, 13, 16, 17 and 18. The remaining views all show Blackjack.

17


18


89

RESTRICTED

HOME OFFICE
Horseferry House, Dean Ryle Street, London, SW1P 2AW

Direct line: 01-211
Switchboard: 01-211 3000
Telex: 24986

Our reference: CDP/73 86/11/15
Your reference:

The information given in this circular is not to be communicated directly or indirectly to the Press or to any person not specifically authorised to receive it.

Chief Executive

County Councils) in England and Wales
District Councils)

London Borough Councils

The Town Clerk, City of London

The Director General

The Greater London Council

The Chief Officer of Police

18 February 1976

Dear Sir,

Home Office Circular No. ES 3 /1976

Briefing Material for Wartime Controllers

The classified information contained in this circular is part of some background briefing given to certain officers designated to be senior members on the staff of the regional and sub-regional commissioners in war. It has been decided that it would be prudent to give the same information to London group, London borough, county and district controllers (designate) and chief officers of police in England and Wales.

2. It is emphasised that in normal peacetime, as opposed to a crisis period when the Government of the day may decide to institute preparatory measures to put the country onto a war footing, the recipients of this circular should not normally convey its contents to persons other than those holding the posts listed in the paragraph above. Exceptionally the information or a part of it may be passed by the recipient to a controller's deputy or seniorstaff officer on a strict "need-to-know" basis.

3. The circular deals briefly in the context of a nuclear war with four topics: law and order, the use of surviving industrial resources, manpower and the collapse of the monetary economy. A small part of this information has already appeared in other ES guidance circulars, with which this circular is to be read. Any urgent queries on it should be sent under plain sealed cover to the Assistant Secretary, Emergency Services (F.6) Division, Home Office. Additional copies are not available and should not be reproduced without the prior consent of the Home Office (F.6)

Law and Order

4. In conditions of anarchy, the implementation of measures necessary for national survival would be impossible and the maintenance of public order would be one of the essential tasks of wartime regional government. Responsibility for preventing a major breakdown of order would fall mainly on the police, supported where necessary by the armed forces. The police actions would be backed by a regional system of courts, with emergency powers (see paragraph 7 below).

5. The main resources of the wartime judicial and penal system would be concentrated against the anti-social conduct of individuals, which seriously interfered with the essentials of the life of the community. However, at a time when the paramount aim would be survival, certain conduct which would be regarded as anti-social in peacetime (e.g. the occupation of empty buildings, or the appropriation of unused chattels to one's own use) might well be condoned, provided that the act did not involve violence and was not immediately prejudical to the life of another individual.

6. In conditions in which death, destruction and injury were commonplace, such penalties as probation, fines or sentences of imprisonment would no longer be effective in dealing with anti-social offenders. Such penalties as communal labour, restricted rations and exposure to public disapproval might be appropriate for all but the gravest offences, but in the case of flagrantly anti-social behaviour there might be a need for harsher penalties than would be generally acceptable in peacetime. Provision for appropriate penalties, not normally available to courts, would be made under emergency regulations, and Regional Commissioners, acting through their commissioners of justice, would be empowered to impose such penalties as they thought fit in the light of conditions and circumstances at the time.

7. All persons holding any form of judicial office and all active justices of the peace would be eligible to sit in emergency courts. It would therefore be possible to hold an emergency court anywhere in a region, where radiological conditions permitted movement. Lay commissioners would normally sit in pairs, or as a bench of three, but if necessary a commissioner sitting alone would still constitute a court. In capital cases, wherever practicable, there would be a jury of not more than five, empowered summarily, or a court consisting of not less than three commissioners. In other cases, commissioners would sit with or without a jury as they saw fit. Cases which in peacetime would be triable summarily would not be expected to have a jury. There would be no appeals, but the senior commissioner would make arrangements to review decisions of the emergency courts in his area.

Use of Surviving Industrial Resources

8. A large scale nuclear attack would disrupt the production and distribution of power supplies, and hence most industrial and commercial activities, nearly everywhere in the United Kingdom. Individual electricity generating and switching stations might be destroyed or damaged beyond repair and the electricity grid system might also be destroyed or disrupted in many areas. Similar damage would be caused to gas production and distributing plant. Coal stocks would vary throughout the country, but in some regions they would be very low and transport difficulties would cause problems of distribution. Oil stocks would be seriously depleted through the destruction of refineries and storage installations, and there would be little prospect of significant imports for some months after attack. Regional Commissioners would therefore have the urgent task of determining how to put the remaining power resources to the best possible use.

9. The first task would be to identify surviving stocks of raw materials and essential manufactured goods, and to establish priorities for the restoration of industries essential to survival. Restoration of the power industries would clearly be of the highest priority, followed by such industries as those concerned with the production and processing of food and water, medical supplies and building materials. Because of the lack of adequate supplies of fuel and raw materials, improvised methods of production would have to be developed for many essential goods; machinery would have to be cannibalised for spare parts and in many cases mechanical methods of production, dependent on adequate power supplies, would have to be replaced by processes which could be performed by manual labour. The highly mechanised agricultural industry, in particular, would have to revert to more primitive methods of working for some time to come.

10. The transport of essential supplies would present serious problems. The railway system would be badly disrupted, not only because of the destruction of tracks, signalling equipment and rolling stock, but also due to a shortage of electricity and diesel fuel. There would be little fuel for road vehicles, and spare parts would have to be obtained through cannibalisation. The use of inland waterways would be restricted through damage to locks, embankments and aqueducts, although short stretches might be navigable by barges and some use might be made of small boats and rafts propelled manually.

11. The repair of damaged houses would be restricted by the scarcity of all building materials and the demands of existing supplies for equally urgent tasks in essential industries and services. Such work as patching and weather proofing, done by self-help or perhaps by teams of volunteers organised by local authorities, would be dependent on the use of salvaged materials. Repairs would have to be confined to the more lightly damaged areas: any attempt to restore the more badly damaged towns and cities would be totally beyond the resources available, and the main activity in these areas, when radiological levels permitted movement into them, would be the salvaging of usable building materials.

Manpower

12. In spite of heavy casualties among the able-bodied population, there should be no general shortage of manpower, since industry, as it existed before the attack, would be virtually at a standstill. The problem would be to make the best use of the manpower resources available. In the immediate aftermath of a nuclear attack one aim would be to provide as many people as possible with some form of useful work to sustain morale. At this stage, however, the main demand would be for heavy manual labour, for such immediate tasks as the clearance of roads, emergency sanitation and the burial of the dead. With insufficient food and no balanced diet available, there would be an added reluctance to undertake heavy or unpleasant work.

13. Regional Commissioners would have statutory powers to direct labour, but in the absence of effective sanctions, short of summary execution, for dealing with those who might not comply with directions, success in the allocation of labour throughout the survival period would in practice depend on the community's acceptance of the need and their voluntary co-operation. The difficulty would be to provide incentives. Money would have no value, and initial rewards for labour might be a meal or extra food for the family. Fortunately most of the tasks would be seen to relate to local improvement in living conditions.

Collapse of the Monetary Economy

14. A large scale nuclear attack on this country would completely disrupt the banking system on which the whole monetary economy is based. Even a small scale

attack on London and the location of the major facilities of big clearing banks would have a similar effect. In a situation where power supplies would be cut off, public and private transport brought to a standstill, and industrial and commercial activities halted, the major sources of income would dry up. In the survival period, when all efforts would be concentrated on providing the barest essentials of life, money in its present form would cease to have any significance. Some token exchange for goods, services and manual effort might be needed, and to this extent it might be feasible to allow the use of existing currency. In practice, however, it seems likely that for some time after an attack, until essential industrial production could be restarted, barter and the government issue of food and clothing would prevail. It may therefore be assumed that, for a period at least, the widespread use of money, as a means of purchasing goods or rewarding services, would cease.

15. It would be an essential part of the policy for national recovery to re-establish a new monetary system as soon as possible. This might take a year or more, depending on the scale of the attack, and it could not be assumed that the old currency would be redeemed, except possibly at a considerable devaluation of its earlier purchasing power. The creation of a new monetary system would be a national matter and not one in which individual Regional Commissioners could devise their own policies. The interim use and value of money would vary from region to region in the survival period. Regional Commissioners would be assisted in these monetary and other economic problems by financial advisers drawn from the Treasury and the private sector.

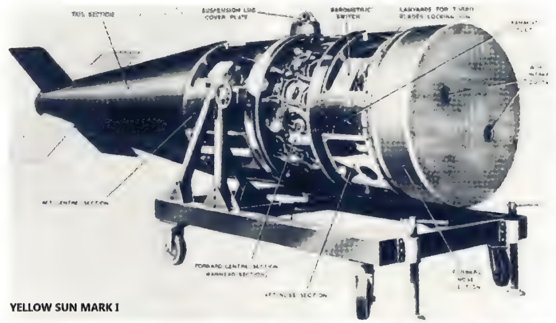
Yours faithfully,

J. F. D. Buttery

J. F. D. BUTTERY

25 kt composite core (Pu239 within U235) tactical air burst on 9 October 1957, held by balloon at 300m altitude, Maralinga

800 kt double-secondary ("Penney's full Tom, Dick and Harry", all spherically shaped) strategic air burst on 11 September 1958 at 2.65km altitude, Christmas Is.



RED BEARD TACTICAL WEAPON LOADED ON TO A BLACKBURN BUCCANEER JET

1 Mt RED SNOW (UK VERSION OF W28)

SUBJECT	COMPONENT PARTS
War and natural disasters.	National organisation for Home Defence. Local Government organisation for Home Defence. The Warning and Monitoring Organisation. The effects of Nuclear explosions. The effects of Biological and Chemical Warfare.
The organisation of National resources in peace and war.	Fuel. Power. Water. Labour. Transport - air, sea and land. Food.
The organisation and functioning of the Health Service. (including the Ambulance Service).	The Regional Hospital Boards. The Hospitals. The Public Health Service. The General Practitioner and Domiciliary Services.
The organisation and functions of the Police and Fire Services.	Manpower. Equipment. Capabilities. Communications.
Central and Local Government communication systems and capabilities.	Broadcasting. Television. Post Office systems: Telephone Telex Teleprinters. Radio Systems.
Social and mass psychology and morale.	Motivation. Leadership. Incentives. Behavioural attitudes under stress.
Modern management concepts and techniques (including man Management).	Statistical analysis and the computer. Organisation and functions of O & M, and Work Study. Operational Research. Human relations. Management by objectives.

PROTECT AND SURVIVE

Issued by H.M. Government

How to make your home as safe as possible under nuclear attack. Read this with care and keep it handy. Your life and the lives of your family may depend on it.

If Britain is attacked by nuclear bombs or by missiles, we do not know what targets will be chosen or how severe the assault will be.
If nuclear weapons are used on a large scale, those of us living in the country areas might be exposed to as great a risk as those in the towns. The radioactive dust, falling where the wind blows it, will bring the most widespread dangers of all. No part of the United Kingdom can be considered safe from both the direct effects of the weapons and the resultant fall-out.
The dangers which you and your family will face in this situation can be reduced if you follow the advice on these pages.

1 Challenge to survival

Everything within a certain distance of a nuclear explosion will be totally destroyed. Even people living outside this area will be in danger from –

HEAT AND BLAST

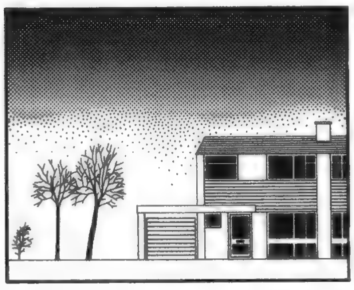
FALL-OUT

Heat and Blast

The heat and blast are so severe that they can kill, and destroy buildings, for up to five miles from the explosion. Beyond that, there can be severe damage.

Fall-out

Fall-out is dust that is sucked up from the ground by the explosion. It can be deadly dangerous. It rises high in the air and can be carried by the winds for hundreds of miles before falling to the ground.
The radiation from this dust is dangerous. It cannot be seen or felt. It has no smell, and it can be detected only by special instruments. Exposure to it can cause sickness and death. If the dust fell on or around your home, the radiation from it would be a danger to you and your family for many days after an explosion. Radiation can penetrate any material, but its intensity is reduced as it passes through – so the thicker and denser the material is, the better.



2 Planning for survival

Stay at Home

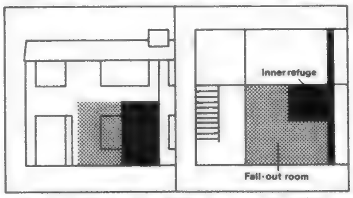
Your own local authority will best be able to help you in war.
If you move away – unless you have a place of your own to go to or intend to live with relatives – the authority in your new area will not help you with accommodation or food or other essentials.
If you leave, your local authority may need to take your empty house for others to use. So stay at home.

Plan a Fall-out room and Inner Refuge

The first priority is to provide shelter within your home against radioactive fall-out. Your best protection is to make a fall-out room and build an inner refuge within it.

First, the Fall-out room

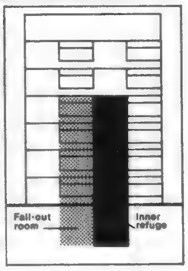
Because of the threat of radiation you and your family may need to live in this room for fourteen days after an attack, almost without leaving it at all. So you must make it as safe as you can, and equip it for your survival. Choose the place furthest from the outside walls and from the roof, or which has the smallest



amount of outside wall. The further you can get, within your home, from the radioactive dust that is on or around it, the safer you will be. Use the cellar or basement if there is one. Otherwise use a room, hall or passage on the ground floor.
Even the safest room in your home is not safe enough, however. You will need to block up windows in the room, and any other openings, and to make the outside walls thicker, and also to thicken the floor above you, to provide the strongest possible protection against the penetration of radiation. Thick, dense materials are the best, and bricks, concrete or building blocks, timber, boxes of earth, sand, books, and furniture might all be used.

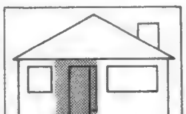
Flats

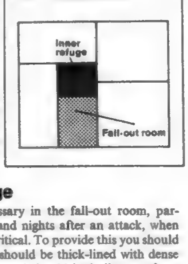
If you live in a block of flats there are other factors to consider. If the block is five storeys high or more, do not shelter in the top two floors. Make arrangements now with your landlord for alternative shelter accommodation if you can, or with your neighbours on the lower floors, or with relatives or friends.
If your flat is in a block of four storeys or less, the basement or ground floor will give you the best protection. Central corridors on lower floors will provide good protection.



Bungalows

Bungalows and similar single-storey homes will not give much protection. Arrange to shelter with someone close by if you can do so.
If not, select a place in your home that is furthest from the roof and the outside walls, and strengthen it as has been described.





Caravans

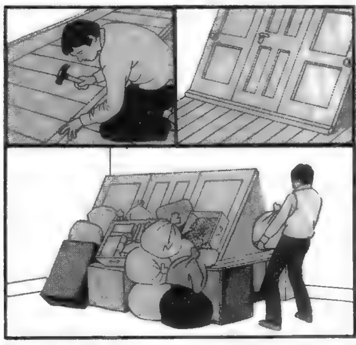
If you live in a caravan or other similar accommodation which provides very little protection against fall-out your local authority will be able to advise you on what to do.

Now the Inner Refuge

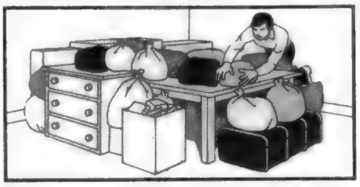
Still greater protection is necessary in the fall-out room, particularly for the first two days and nights after an attack, when the radiation dangers could be critical. To provide this you should build an inner refuge. This too should be thick-lined with dense materials to resist the radiation, and should be built away from the outside walls.

Here are some ideas:

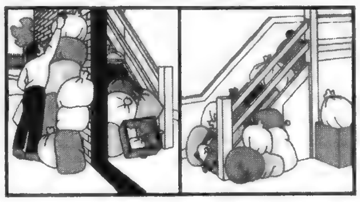
1. Make a 'lean-to' with sloping doors taken from rooms above or strong boards rested against an inner wall. Prevent them from slipping by fixing a length of wood along the floor. Build further protection of bags or boxes of earth or sand – or books, or even clothing – on the slope of your refuge, and anchor these also against slipping. Partly close the two open ends with boxes of earth or sand, or heavy furniture.



2. Use tables if they are large enough to provide you all with shelter. Surround them and cover them with heavy furniture filled with sand, earth, books or clothing.



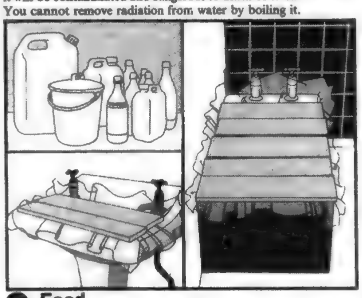
3. Use the cupboard under the stairs if it is in your fall-out room. Put bags of earth or sand on the stairs and along the wall of the cupboard. If the stairs are on an outside wall, strengthen the wall outside in the same way to a height of six feet.



PLAN YOUR SURVIVAL KIT
Five essentials for survival in your Fall-out Room

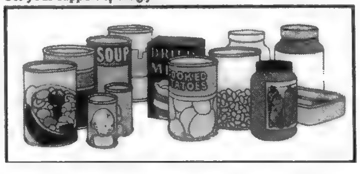
1 Drinking Water

You will need enough for the family for fourteen days. Each person should drink two pints a day – so for this you will need three and a half gallons each.
You should try to stock twice as much water as you are likely to need for drinking, so that you will have enough for washing. You are unlikely to be able to use the mains water supply after an attack – so provide your drinking water beforehand by filling bottles for use in the fall-out room. Store extra water in the bath, in basins and in other containers.
Seal or cover all you can. Anything that has had fall-out dust on it will be contaminated and dangerous to drink or to eat.
You cannot remove radiation from water by boiling it.



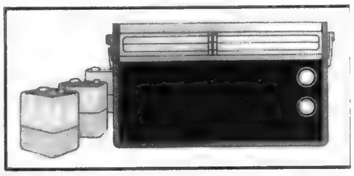
2 Food

Stock enough food for fourteen days.
Choose foods which can be eaten cold, which keep fresh, and which are tinned or well wrapped. Keep your stocks in a closed cabinet or cupboard.
Provide variety. Stock sugar, jams or other sweet foods, cereals, biscuits, meats, vegetables, fruit and fruit juices. Children will need tinned or powdered milk, and babies their normal food as far as is possible. Eat perishable items first.
Use your supplies sparingly.



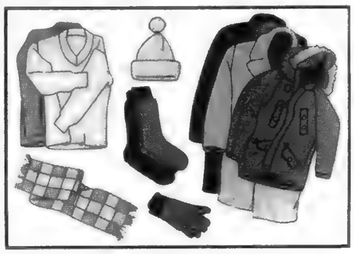
3 Portable Radio and Spare Batteries

Your radio will be your only link with the outside world. So take a spare one with you if you can.
You will need to listen for instructions about what to do after the attack and while you remain in your fall-out room.



4 Tin Opener, Bottle Opener, Cutlery and Crockery

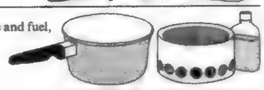
5 Warm Clothing



These further items will also be useful in the Fall-out Room:

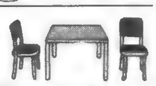
6. Bedding, sleeping bags

7. Portable stove and fuel, saucepans

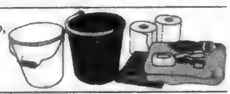


8. Torches with spare bulbs and batteries, candles, matches

9. Table and chairs



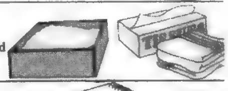
10. Toilet articles, soap, toilet rolls, bucket and plastic bags



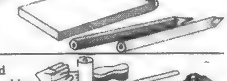
11. Changes of clothing

12. First aid Kit – with household medicines and prescribed medicines. And at least Aspirins or Codeine tablets, adhesive dressings, cotton wool, bandages, disinfectant, ointment, including 'Vaseline'

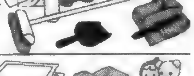
13. Box of dry sand, cloths or tissues for wiping plates and utensils



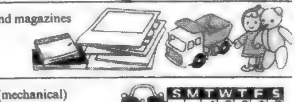
14. Notebook and pencils for messages



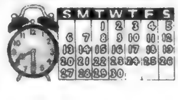
15. Brushes, shovels and cleaning materials, rubber or plastic gloves, dustpan and brush



16. Toys and magazines



17. Clock (mechanical) and calendar



FROM: "Royal Observer Corps Journal", Feb. 1985, page 26

FRAGMENTS

Feb. '85:
UK, Home Office "FISSION FRAGMENTS" article, reprinted in ROC Journal V27n2

PROTECTION AGAINST RADIATION

A. L. Mather ex-SA, Northumberland

In 'Protect and Survive' a recommendation is made on page 11 para. 2 'Use tables if they are large enough to provide you all with shelter. Surround them and cover them with heavy furniture filled with sand, earth, books or clothing'. Similar shelters are proposed in paras 1 and 3.

Apart from the fact that under certain circumstances of location and weather sufficient soil may not be available, none of the materials suggested for radiation protection is of use to the shelter-bound occupants. The use of survival supplies as a radiation barrier is to be recommended, if not, indeed considered essential. As previously suggested fuel supplies, which have a half value thickness approaching that of soil, could be used in this way. Food supplies should be stacked in boxes as the inner protective barrier together with immediate water supplies. Water has a half value thickness of 200mm compared with 140mm for earth. One therefore has only to create a water barrier 50% greater in width to equate with a soil barrier. The water barrier can be erected in a very short time merely by filling suitable containers by means of a hosepipe. In this way an adequate shelter can be made in a fraction of the time needed for the filling and transportation of sandbags. Further this would provide a strategic supply of water for fire fighting, drinking, washing and for the later survival period during which water supplies may be limited.

Cheap containers would be needed for such a barrier and dustbins, plastic bottles etc would be expensive and inconvenient to store when not required. There is, however, a suitable container made by Bowater Scott Ltd (and possibly by other companies) which is used for the conveyance of milk. These are double walled plastic bags of five gallon capacity with screw caps. The bags are supplied flat together with fold flat heavy duty cardboard boxes. When the box is erected and the plastic bag within is filled, it takes the shape of the box and forms a fairly rigid 'brick' of water of dimensions 25 cm × 24 cm × 42 cm. These bricks may be stacked to a height of 4 units (on their side) without bursting or collapsing. The bags are very strong and access may be made to them by cutting a sealed plastic tube which is attached to the screw top. Additives would be required to prevent the growth of algae or bacteria.

Not only can one stack these water bricks above and around the shelter but these could also be put on upper and attic floors to improve radiation protection in the fall out room. It would also improve fire protection in the upper floor of the building. The cost of these bags is low (£592 per 1000 including cardboard box). Doubling the thickness of the box to improve stacking properties would increase the cost of the box by 50%. No doubt the price could be improved by simplification of design and by mass production.

One weakness of such a system is the susceptibility of the water bags to rupture by blast damage. Those bags exposed to windows or openings should be protected by a suitable tough barrier such as carpets, heavy timber and/or doors.

There would be load limitations on some types of floor and this aspect would need to be discussed with builders before installation. However as the half thickness for water is larger than that for soil then the equivalent weight of water would be spread over a larger area of the floor.

The progressive reduction of radiation being received by the shelter will allow the progressive use of water from the radiation barrier. The empty water bags may be used to store waste liquids.

This system would perhaps find its primary application to indoor shelters but there is no reason why water may not be used to supplement barriers in other types of shelter. The containers in collapsed form are compact and may be stored in lofts or sheds. In an emergency the barrier may be erected and filled by a hosepipe in a very short period of time without any great effort. This would be of considerable help to elderly or infirm people and, in fact, to most people with only a short time to construct a shelter.

First Chinese thermonuclear test 3.3 megatons at 3km altitude, 17 June 1967

U. S. AIR FORCE
PROJECT RAND

RESEARCH MEMORANDUM

SOME INDICATIONS OF SOVIET VIEWS ON THE STRATEGIC EMPLOYMENT OF CW/BW

Leon Gouré

RM-2725

March 16, 1961 **Copy No.____**

This research is sponsored by the United States Air Force under contract No. AF 49(638)-700 monitored by the Directorate of Development Planning, Deputy Chief of Staff, Development, Hq USAF.

The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

and 16 inches high, containing activated charcoal, a chemical absorbant, and a mechanical filter. There may be indicators to show the presence of CW/BW agents in the cannisters. The unit has an electrically and hand operated blower.

The types of shelters which, according to Soviet specifications, are equipped with doors and filter ventilation units include deep shelters, large detached shelters, subways, and basement shelters. These types of shelters have been built in the Soviet Union in varying numbers. While there are no data on the total number of shelters or on the total shelter capacity, it is tentatively estimated that in 1960 there was sufficient shelter space in all types (excluding subways) for 24 to 55 million persons, or for 35 to 40 per cent of the residents in cities of over 50,000 inhabitants and in key economic areas.[3] A recent British Joint Intelligence Bureau report estimates the total Soviet shelter capacity at 30 per cent of the urban population or 33 million persons.[4] While the capacity of individual detached and heavy shelters may be quite large, basement shelters are preferably designed for 100 to 150 persons.

---

[3]Gouré, RM-2564 (see above, p. 1), and also RM-2684, <u>The Soviet Civil Defense Program: A Trip Report</u> (U) (Secret/NOFORN) January 5, 1961.

[4]<u>Air Ministry, Secret Intelligence Summary</u>, "JIB, Intelligence Digest," (Secret), No. 10, Vol. 15, October 1960, p. 27.

It is not known whether all existing shelters are fully equipped according to Soviet specifications and especially whether they all have filter ventilation units and airtight doors. Many intelligence reports indicate their existence in large numbers of shelters. The subway stations in Moscow, Leningrad, and Kiev, according to recent observations, are also equipped with blast doors at the entrances to most of the lower platforms.[5] It must be assumed that the Soviet civil defense authorities intend to provide all existing permanent shelters with doors and filter ventilation facilities.

2. Individual Means of Protection.

Soviet civil defense doctrine specifies that in the event of war each Soviet citizen must have a gas mask and if possible protective clothing and individual decontamination packets to protect him against CBR agents, in case the shelter is damaged or he must leave it soon after an attack. In the compulsory training program people have been instructed in the correct use of these individual means of protection.

The Soviet civilian gas masks appear to be of excellent quality and they have been produced in various sizes for a number of years. They are equipped with double outlet valves to guard

[5]See Gouré, RM-2684.

in its capability to use CW/BW strategically and tactically and better prepared to protect its population and economy against such weapons, Moscow might conclude that its advantage lay in trying to avoid the use of nuclear weapons by either side.

=> LIKE NEUTRON BOMB!!

Soviet spokesmen often point out that CW/BW has the advantage of not destroying industry or buildings. In a general war, the Soviet planners might therefore prefer to use CW/BW weapons rather than nuclears against the Western European countries, whose territory the Soviet Union would doubtless expect to occupy and whose industry and economy they would wish to exploit for their own benefit.

It is conceivable that future developments in CW/BW could lead to a great improvement of the effectiveness of such weapons in terms of toxicity and area coverage, so that their strategic employment, especially by surprise against an unprepared enemy, might be deemed preferable to the use of nuclear weapons.

* * * * *

The above cases, of course, are entirely hypothetical; they are not based on careful analysis of the military worth of specific CW/BW weapons or alternative Soviet strategies. Even as speculative suppositions they are not exhaustive. The author does believe, however, that the attempts made to ascertain Soviet strategic doctrine, particularly on any employment of CW/BW,

DEFENCE REGULATIONS

IMPORTANT ANNOUNCEMENT

BILLETING

The Government have announced that the dispersal of people in priority classes from certain large towns shall be put into effect immediately.

The area covered by the...Council is a reception area* to which some of these people are being brought.

Occupiers of housing property in this area are required by law to provide accommodation for any persons assigned to them by the Billeting Officer. Every effort will be made to spread the burden of billeting fairly and equally between households.

It may be necessary to carry out billeting at night as well as day-time. Your co-operation in this emergency is requested.

An allowance will be paid to occupiers for the accommodation provided. To claim this you will need a billeting allowance order form. Watch the bottom of this notice for further information about how to obtain the form.

CLERK OF THE COUNCIL

***If only part of the area is scheduled as a reception area, the districts affected are shown below:**

B 276045

Copy for Occupier

DEFENCE REGULATIONS

BILLETING NOTICE

To the Occupier named below. Under Defence Regulations you are hereby required to provide in the undermentioned premises, lodging (including use of washing and toilet facilities), and cooking facilities/food/attendance (as indicated) for the persons listed on this notice.

Name of Occupier..........

Address of Occupier..........

List of persons billeted

Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging Cooking Facilities Food Attendance

Signature of Billeting Officer.......... Date..........

Local Authority

INSTRUCTIONS TO OCCUPIERS

You cannot charge any person so assigned to you for the accommodation you are required to provide, but you will receive payment at a weekly rate stated in the Billeting Allowance Order Form which will be sent to you as soon as possible.

Should you fail to carry out the requirements of this notice you will commit an offence.

B 276045

DEFENCE REGULATIONS

BILLETING ALLOWANCE ORDER FORM

The occupier named below is entitled to receive the amount shown in the Order at any Post Office within one calendar month of the date on which payment is due.

Name of Occupier..........

Address of Occupier..........

List of persons billeted

Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging * Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging * Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging * Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging * Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District..........	Age if under 18..........	Lodging * Cooking Facilities Food Attendance

Signature of Billeting Officer.......... Date..........

* Billeting Officer to delete as appropriate.

Local Authority

B 276045

BILLETING ALLOWANCE ORDER 9

Due on and not before	Not exceeding **15** POUNDS
	£ s. d.

..........Pounds

..........Shillings

..........Pence

To the Postmaster-General: *The person named above as the occupier is entitled, after signing the declaration, to receive the sum shown on this Order within* **1 CALENDAR MONTH** *of the due date.*

I declare that I am entitled to the above sum.

I acknowledge the receipt of the above sum.

....

(Signature)

PAYING OFFICE STAMP WITH DATE OF PAYMENT

NOT TRANSFERABLE

WARNING—PAYMENT CANNOT BE MADE IF

CUT HERE

B 276045

BILLETING ALLOWANCE ORDER 9

Due on and not before	Not exceeding **15** POUNDS
	£ s. d.

..........Pounds

..........Shillings

..........Pence

To the Postmaster-General: *The person named above as the occupier is entitled, after signing the declaration, to receive the sum shown on this Order within* **1 CALENDAR MONTH** *of the due date.*

I declare that I am entitled to the above sum.

I acknowledge the receipt of the above sum.

....

(Signature)

PAYING OFFICE STAMP WITH DATE OF PAYMENT

NOT TRANSFERABLE

WARNING—PAYMENT CANNOT BE MADE IF

This Form is Government property and should be surrendered to the Billeting Officer immediately any of the persons mentioned overleaf ceases to be billeted on you. A new Form will be issued to you, if necessary.

(1)

Date stamp of Post Office of payment

(2)

NOTE.—If you are too ill or infirm to go to the Post Office you should sign the order overleaf and complete Part 1 below, but you should not do so before the due date of payment ; your agent should sign Part 2.

Part 1. I am too ill or infirm to go to the Post Office and I authorise ....
to receive, as my agent, the amount due to me on this order.

Signature of Payee..
(or mark and name of Payee)
Date..........................

Witness to mark ....
(NOTE: The witness must be a person other than the agent)

Part 2. I am the authorised agent. I certify that the payee is alive today. I acknowledge receipt of the amount shown overleaf which I will pay to the payee forthwith.

Signature of Agent ....
Date..........................

NOTE.—If you are too ill or infirm to go to the Post Office you should sign the order overleaf and complete Part 1 below, but you should not do so before the due date of payment ; your agent should sign Part 2.

Part 1. I am too ill or infirm to go to the Post Office and I authorise ....
to receive, as my agent, the amount due to me on this order.

Signature of Payee..
(or mark and name of Payee)
Date..........................

Witness to mark ....
(NOTE: The witness must be a person other than the agent)

Part 2. I am the authorised agent. I certify that the payee is alive today. I acknowledge receipt of the amount shown overleaf which I will pay to the payee forthwith.

Signature of Agent ....
Date..........................

Copy for Local Authority use

DEFENCE REGULATIONS

BILLETING NOTICE

WITH STATEMENT OF ALLOWANCE

To the Occupier named below. Under Defence Regulations you are hereby required to provide in the undermentioned premises, lodging (including use of washing and toilet facilities), and cooking facilities/food/attendance (as indicated), for the persons listed on this notice.

Name of Occupier..

Address of Occupier...

List of persons billeted

Name .... Last Permanent Address .... Town and District....................................	Age if under 18.........	Lodging Cooking Facilities Food Attendance
Name .... Last Permanent Address .... Town and District....................................	Age if under 18.........	Lodging Cooking Facilities Food Attendance
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Name .... Last Permanent Address .... Town and District....................................	Age if under 18.........	Lodging Cooking Facilities Food Attendance

Signature of Billeting Officer.................................... *Date*..........................
Local Authority

Due on and not before

£ s. d.
Pounds
Shillings
Pence

Due on and not before

£ s. d.
Pounds
Shillings
Pence

IF AIR WAR COMES

A Guide to Air Raid Precautions and Anti-Gas Treatment

by Dr.
L. HADEN GUEST
M.C.
Formerly Medical Instructor, Air Raid Precautions Dept., Home Office

With a Foreword by the Rt. Hon.
The Viscount
DAWSON OF PENN
P.C., K.C.M.G., K.C.V.O.

PRICE ONE SHILLING NET

IF AIR WAR COMES

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With a Foreword by

THE RT. HON. VISCOUNT

DAWSON OF PENN

P.C., K.C.M.G., K.C.V.O.

1937

EYRE & SPOTTISWOODE

LONDON

FOREWORD

This book is timely. The Author makes it clear that air warfare creates a new situation in that it may directly attack the civil population. Men, women and children and their homes, and the buildings which are necessary to the life of a community would be in danger of destruction. It becomes necessary, therefore, that men and women should know the nature of the risks to which they would be exposed and how to protect themselves therefrom. The citizen will also learn the measures required to protect industry and vital services, and how he may play his part should the occasion arise.

The Author, who is an authority on this subject, has performed a service and this book is to be commended.

Dawson of Penn

May 1937

I
THE ATTACK

On July 9th 1935 the Government of Great Britain issued a circular letter on air warfare to all Local Government Authorities throughout the country. The letter came from the air raid precautions department of the Home Office, which thus announced its existence and warned the country of "the precautionary measures which would be necessary for safeguarding the civil population against the effects of air attack."

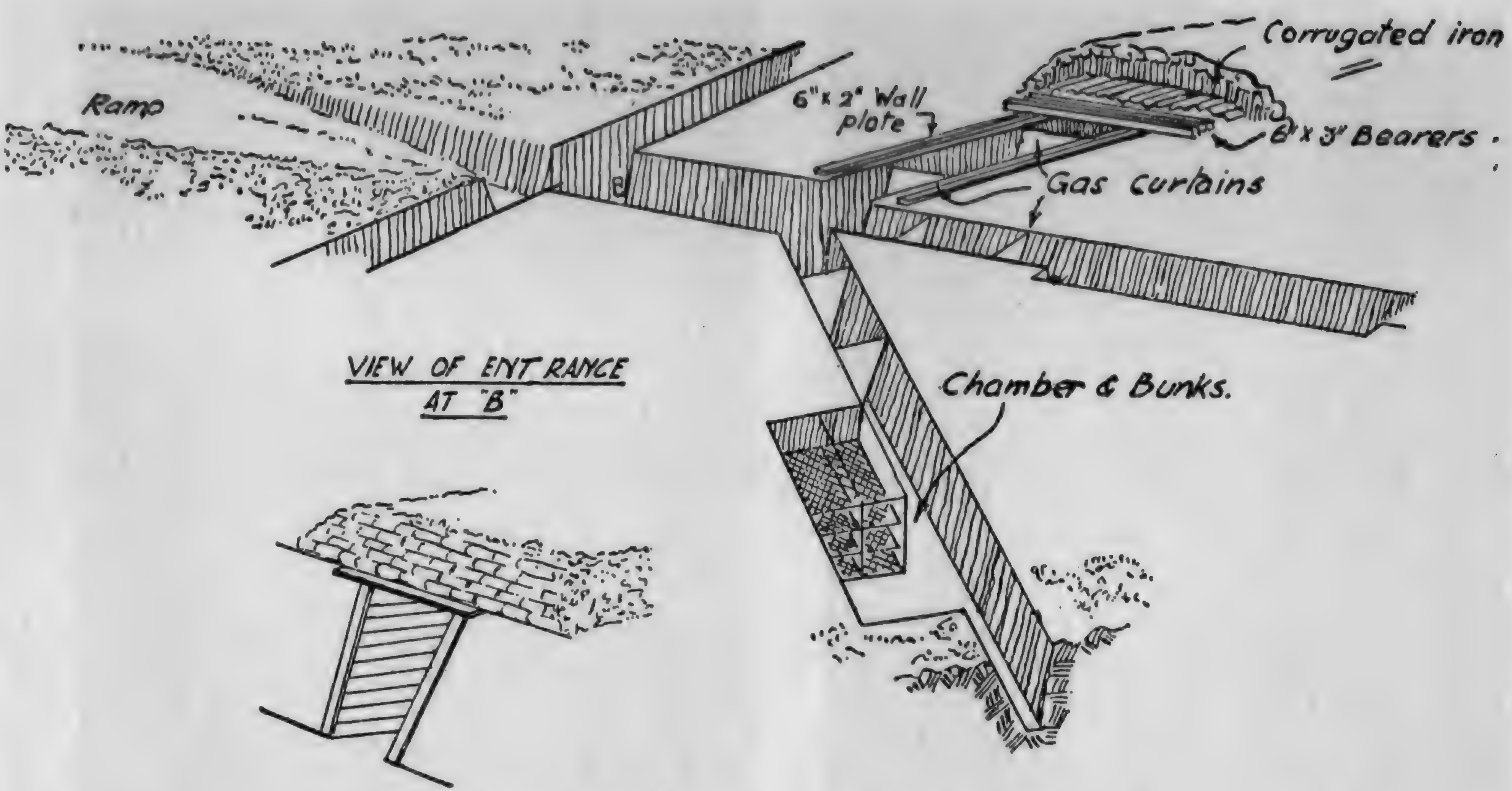
The circular letter went on to say that the need for these measures in no way implies a risk of war in the near future. The letter further said that the unalterable basis of the Government's foreign policy was to promote and ensure peace and to use to the full the machinery of the League of Nations and other instruments for the guaranteeing of peace.

Nevertheless, neither the present Government nor any other can be 100 per cent certain of peace, and the necessity for precautionary measures is clear. Even if the risk of air attack is only one in a hundred no Government can neglect to provide protection for the men, women, and children of the population.

The Government strongly repudiates the idea of attacks on the civil population by means of indiscriminate bombing and goes on to say that the use of poison gas in warfare is forbidden by the Geneva Gas Protocol of 1925. But "the risk of its being used is, nevertheless, a possibility which cannot be disregarded."

Thus Great Britain in 1935 came into line with the Governments of the other Great Powers in Europe and elsewhere who have been organizing "air raid precautions" for two or three years past.

It is admitted, then, that air raids may come to Great Britain. We have to ask, What is the nature of those



RAMP, TRENCH AND AIR-LOCKS

(*Diagram from "Air Raid Precautions in Factories and Business Premises."* A.R.P. Handbook 6. *By kind permission of the Controller, H.M. Stationery Office.*)

26
Manuals
2180

Notified in Army Orders for July, 1939

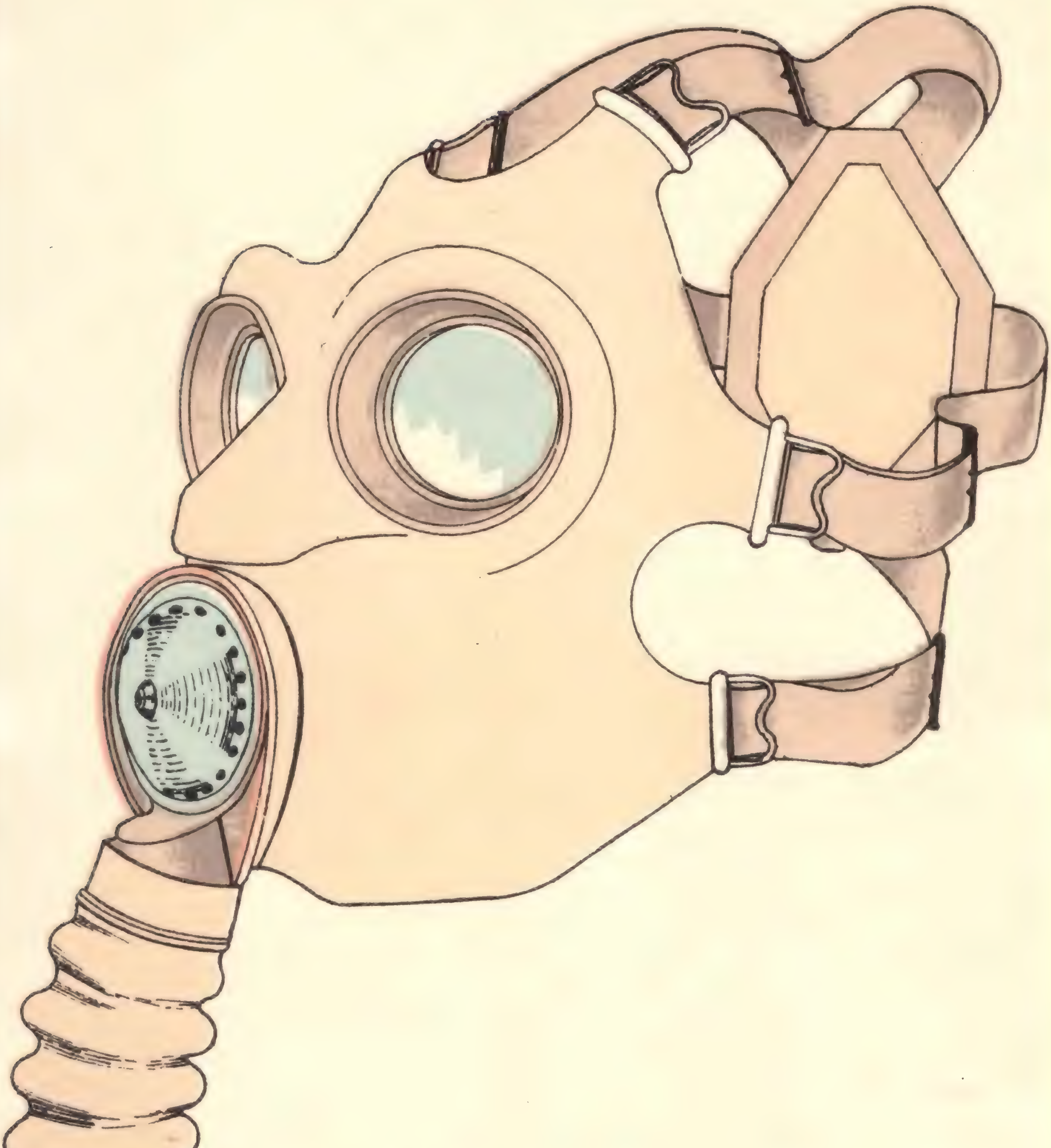
PROTECTION AGAINST GAS AND AIR RAIDS

Pamphlet No. 2
RESPIRATORS

LONDON
PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE
To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:
York House, Kingsway, London, W.C.2; 120 George Street, Edinburgh 2;
26 York Street, Manchester 1; 1 St. Andrew's Crescent, Cardiff;
80 Chichester Street, Belfast:
or through any bookseller

1939

Price 1*s.* 0*d.* net



FACEPIECE

MARK IV.

Fig. I.

147ᴮ 8491. 188,000. 8/39.

Malby & Sons, Lith.

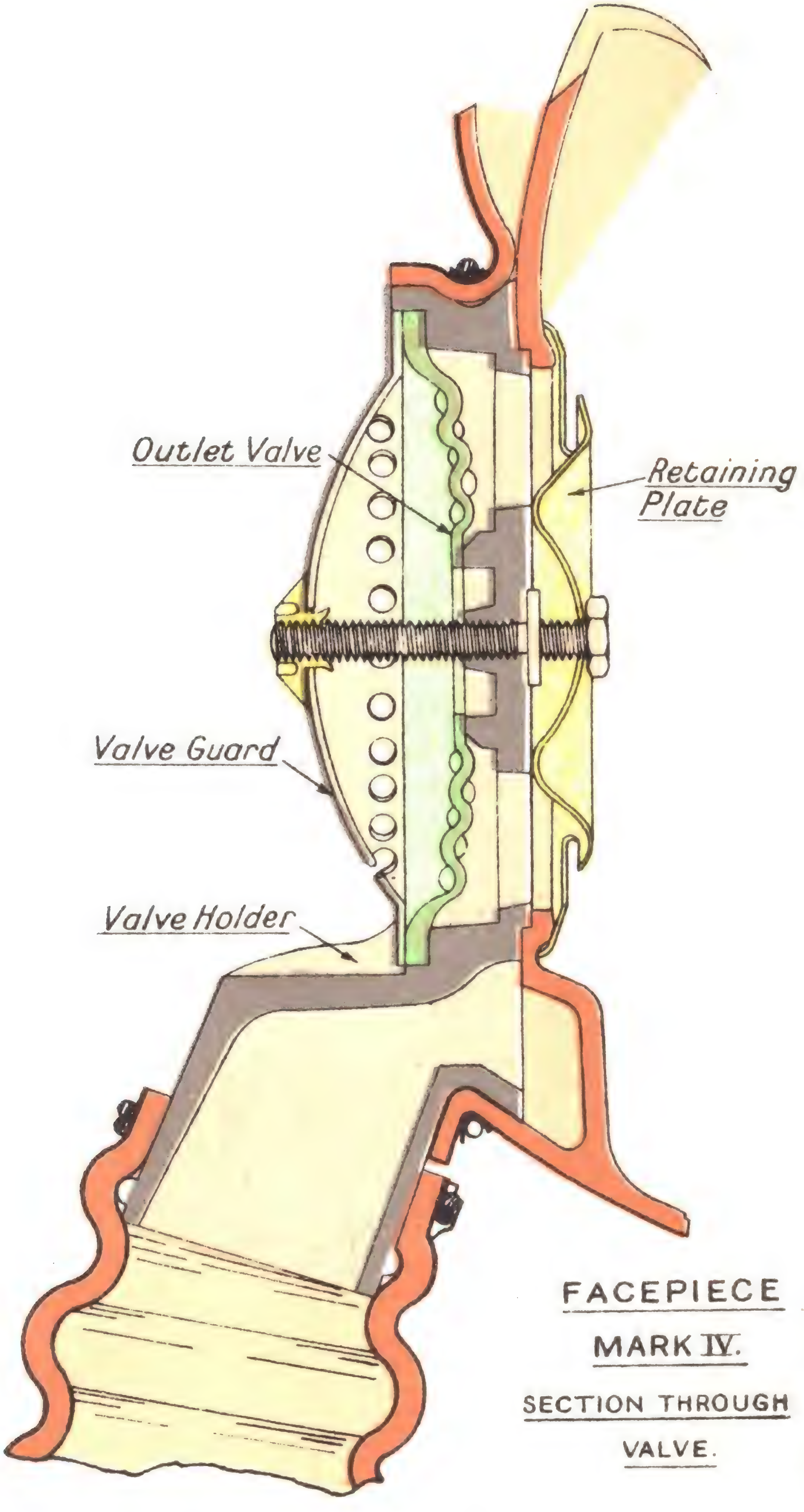

Outlet Valve
Retaining Plate
Valve Guard
Valve Holder
FACEPIECE
MARK IV.
SECTION THROUGH
VALVE.

Fig. 2.

FIG. 3.—SERVICE RESPIRATOR

Facepiece, Mark V. Container, Type E.
Haversack, Mark V. Anti-dimming outfit.

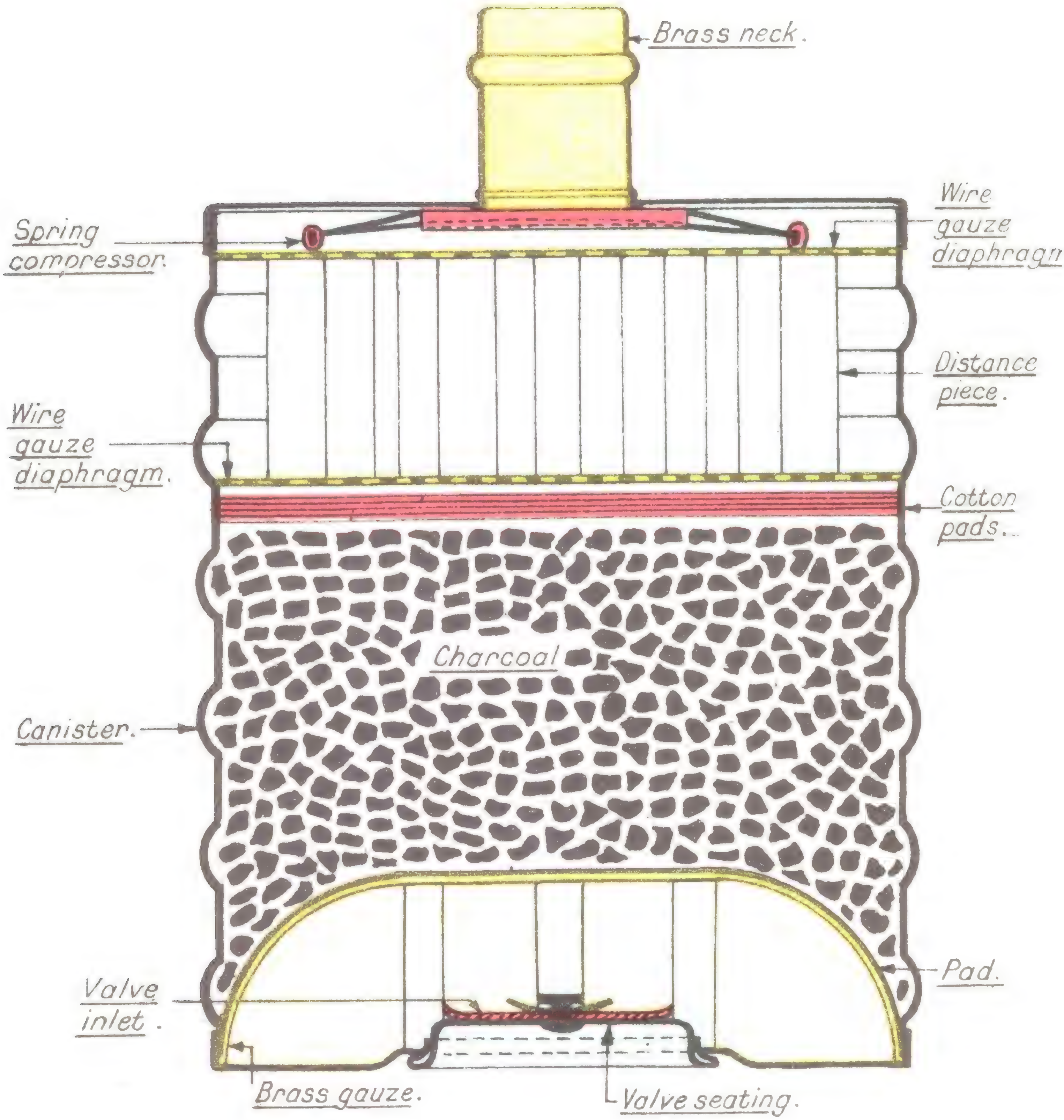
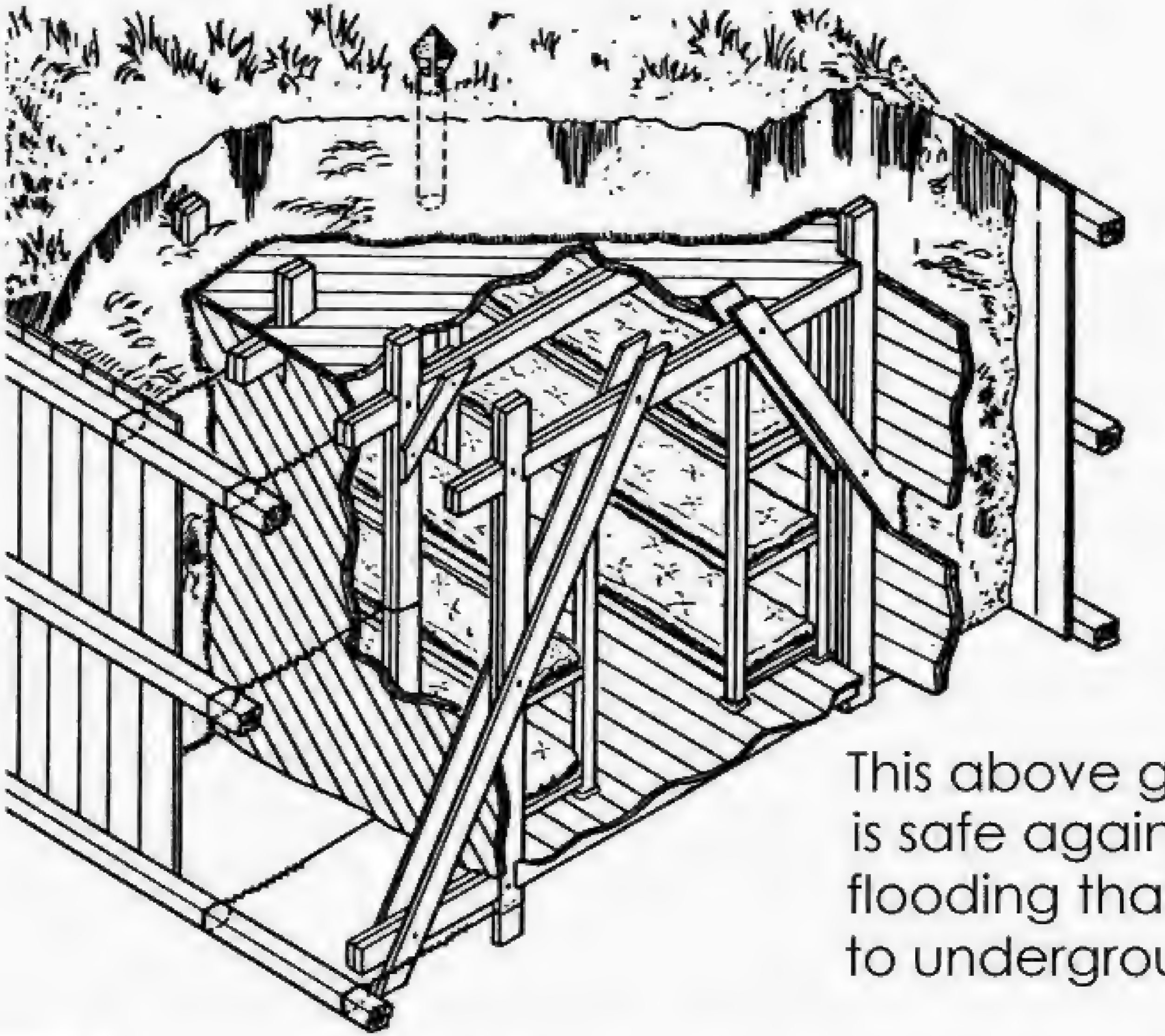


Fig.4.-Container type A.

(Gas masks contained an activated charcoal absorber as shown above to absorb gases evaporated from nerve agents, or chlorine, phosgene, etc. Cotton pad Contex filters were added for particles.)

PROOF-TESTED OUTDOOR ABOVE GROUND WOOD AND EARTH SHELTER



No casualties in test at 20 ft (250 kg TNT)

(Minor damage to shelter from the crater debris)

This above ground shelter is safe against ground water flooding that occurs in winter to underground shelter/trench.

UK *Min. Home S.* Research and Experiments Department Bulletin C26, *Timber shelters for countries where timber is plentiful and steel difficult to obtain,* April 1942. This is a surface (not underground) wooden shelter with 2.5 ft earth fills in the gap between two wooden walls, and on roof. *UK Ministry of Home Security shelter research became Home Office postwar*

HOME OFFICE

CIVIL DEFENCE

RESTRICTED

The information given in this document is not to be communicated either directly or indirectly to the Press or to any person not authorised to receive it

Manual for Technical Reconnaissance Officers

PART 2

Now known as Manual for Scientific Intelligence Officers

The Detection and Identification of War Gases

Consolidated Edition (*incorporating Amendment No. 1*)

LONDON: HER MAJESTY'S STATIONERY OFFICE

Copies will be sold only on written application by a Clerk to a Local Authority, A Chief Constable, A Chief Officer of a Fire Brigade, The Principal of a Public Utility Company or Industrial or Commercial concern or Institution, County Secretaries of the St. John Ambulance Brigade, British Red Cross Society, St. Andrew's Ambulance Association, Headquarters Women's Voluntary Services.—to H.M. Stationery Office at the addresses on p. iv of the cover,

Price 4s. 6d. net

1960: *Reprinted* 1965

CHAPTER 1

The War Gases: Introductory

1. General Considerations

The term "Gas" when used in connection with chemical warfare includes any chemical substance, whether solid, liquid or gas, which is employed in war for its poisonous or irritant effects on the human body.

Theoretically, all substances having such effects could be used as war gases, but in practice a number of other considerations enter. In addition to possessing adequate and utilisable physiological action there is, for example, the question of production—the substance must be relatively cheap, and capable of practical and economical production from available raw materials. Again, it must have suitable physical and chemical properties—its vapour pressure, for example, must be sufficiently high to give effective concentrations under ordinary conditions, and it must be comparatively stable and chemically indifferent so as not to be too rapidly destroyed by atmospheric or other agents.

These considerations limit the choice enormously. It has been estimated that during the war of 1914–18 some three to four thousand substances were examined as to their suitability for use as war gases. Of these, however, only about 54 were ever actually used in the field: and of these again, only 12 were in active use at the end of that war. A few substances have since been suggested as possibilities, but the number still remains reasonably small. The field for our consideration can be still further narrowed if it is remembered that many of the substances thus recently discovered are greatly superior to the earliest war gases in physical properties and physiological action. Many of these older war gases, such as chlorine, KSK, etc., having been outmoded in this way are unlikely to be encountered in modern warfare, and are accordingly excluded from this Manual.

2. Classification

The war gases differ considerably in physical properties and chemical nature, and the only reasonably satisfactory way of classifying them is according to the effects which they produce on the human body. On this basis the gases are divided into five main groups according to whether their predominant action is on the nervous system, the skin, the lungs, the eyes or the nose, this being roughly the order of importance at present assigned to these groups.

Nerve Gases form the most recently discovered group of agents. More toxic than previously known war gases, they may gain entrance to the body by inhalation of the vapour or by absorption of the liquid agent through the skin, the eyes or the gastrointestinal tract. They act on the nervous system, causing contraction of the pupils of the eyes, resulting in dimness in vision and difficulty in focussing on near objects,

accompanied by severe frontal headache. They may also cause running of the nose, and a feeling of tightness in the chest. These symptoms, which normally develop in a few minutes, are followed in severe cases by twitching and convulsions of the limbs, and possibly death. The minor effects persist for some days without treatment, and may give rise to acute discomfort, but in non-fatal cases they cause no permanent damage.

Blister Gases (Skin Irritants or Vesicants), exert an aggressive action on all parts of the body with which they come into contact—eyes, lungs, skin, etc.—whether as vapour or liquid, causing intense irritation, and in severe cases deep and extensive blistering. Their effect, moreover, is more or less delayed; a circumstance which makes them doubly dangerous; no immediate irritation is felt, the symptoms only developing some time after exposure, when it is too late to take protective measures. To this group belong the well-known mustard gas, the arsenical vesicants such as lewisite, and the more recently discovered nitrogen mustard gases.

Choking Gases (Lung Irritants or Asphyxiants) function by their action on the respiratory system, and are highly lethal. They irritate the throat and lungs causing coughing and difficulty in breathing and in severe cases give rise to acute pulmonary oedema. The most important members of this group are phosgene, diphosgene and chloropicrin.

Tear Gases (Eye Irritants or Lachrymators) act as their name implies, on the eyes, causing intense smarting and a profuse flow of tears, but without normally effecting any permanent damage. The members of this group are for the most part halogenated aromatic compounds, typical examples being bromobenzyl cyanide (BBC) and chloracetophenone (CN).

Nose Gases (Nose Irritants, Sternutators) give rise to intense pain in the nose, throat, and chest accompanied by nausea and mental depression. As with tear gases, the effect is only temporary, though the symptoms develop slowly, and may continue for some hours after exposure to the gas. The members of this group are aromatic arsenical derivatives, known for simplicity by their code letters, DA, DC, and DM.

As with most classifications, a certain amount of overlapping occurs; chloropicrin, for example, is quite an efficient lachrymator: nerve gases cause difficulty in breathing: and chloracetophenone in high concentrations has a definite, though temporary, effect on the skin. There are also a few gases which cannot be satisfactorily fitted into the scheme, such as the paralysants, hydrocyanic acid and hydrogen sulphide which function by paralysing the central nervous system, though by a different mechanism from that of the nerve gases, and the haemolytic gas arsine. From the practical aspect, however, the classification is of definite value, in that it stresses the purpose for which the different gases are used, and the dangers to be apprehended from their use.

3. General Properties

Before outlining the characteristics of the individual war gases, it will be convenient to deal generally with their properties as a class,

and in so doing to draw attention to a further, and very important, way of grouping them—namely, classification according to persistence, which depends primarily on considerations of vapour pressure.

Vapour pressure, Volatility, and Persistence. Vapour pressure, which is, of course, closely allied with boiling point, is of particular importance in two directions. In the first place it determines the so-called "Volatility", or Saturation concentration of the gas, i.e., the maximum concentration of vapour which it is possible to obtain under given climatic conditions: and in the second place, it governs the "Persistence" of the gas, which may be roughly defined as the time during which it remains effective at the point of release.

The *Volatility*, which is expressed as weight in milligrams of substance saturating 1 cubic metre of air at the temperature under consideration (or alternatively as parts per million), is obtained by calculation as follows:

If the vapour pressure of the substance is p mm. Hg. at a given temperature t°C., then $\frac{p}{760}$ c.c. of vapour saturate 1 c.c. of air, and $\frac{10^6 p}{760}$ c.c. of vapour saturate 1 cu. m. of air (= parts per million). Or, since the vapour density of the substance, assuming it to be a perfect gas, is $\frac{M}{22{\cdot}4} \times \frac{273}{(273 + t)}$ gms./litre, or mgms./c.c., the Volatility is $\frac{10^6 p}{760} \times \frac{M \quad 273}{22{\cdot}4\ (273 + t)}$ mgms./ cu. m., (M being the molecular weight).

The Volatility is, naturally, of considerable importance in connection with liquids used as lethal war gases, since it is obviously essential that the concentrations obtainable under ordinary conditions should be sufficiently high to be rapidly effective.

As regards *Persistence*, many factors enter, but the most important is the rate of evaporation of the liquid gas, which depends primarily on its vapour pressure—the lower the vapour pressure, the slower the rate of evaporation and the greater the persistence. Making certain assumptions it is possible to estimate the rate of evaporation, and inversely the persistence, of a liquid as compared with that of water under similar conditions, the values so obtained for some of the war gases being given in Table I.

The figures, it should be noted, are essentially relative and have no absolute significance. The actual persistence will depend, *inter alia*, on the weather and the nature of the ground and surface. High temperatures and wind velocities, for example, will favour rapid evaporation: rain will effect a certain amount of mechanical washing away and in some cases destruction by hydrolysis: the persistence will be considerably greater in sheltered terrain than in the open, and similarly will be less if the liquid falls on impervious rocky material on which it spreads without sinking in, than if it falls on a porous material such as sand, where the reverse process will occur.

The chief merit of the figures is to illustrate the fundamental distinction between the non-persistent and the persistent gases. The *non-persistent gases* vaporise rapidly when released, to form a very

concentrated and hence highly toxic cloud, which however, drifts away with the wind and becomes more or less speedily diluted with the atmosphere. On the other hand, the *persistent gases*, when released, contaminate the surrounding ground, etc., with relatively high-boiling liquid which evaporates slowly and continues to give off dangerous vapour for a comparatively long time, making it necessary in certain cases to apply some form of "decontamination" treatment to render it innocuous.

This distinction has an important bearing on the way in which the different gases are likely to be used in warfare. Both non-persistent and persistent gases can be used in shell and bombs, but for more or less obvious reasons, only the really non-persistent type can be released as clouds from cylinders, and only the comparatively persistent as spray from aircraft.

It also has an important bearing on the work of the Scientific Intelligence Officer. With non-persistent gases, if he is on the spot when the gas is released, a very high concentration will be encountered. Normally, however, the gas will be dispersed to a greater or lesser extent by the time he arrives on the scene, and in the case of the very non-persistent gases such as phosgene it will, naturally, be relatively useless to look for samples of materials contaminated with the liquid gas. With persistent gases, on the other hand, owing to their lower vapour pressure, the concentration in the air is never very high, but evidence of ground contamination will almost invariably be found for hours or even days afterwards.

Vapour Density also affects the persistence to some extent, gases lighter than air being more readily dispersed by diffusion, etc., than the heavier ones, which tend to cling to the ground and follow downward currents. All the important war gases have vapour densities considerably greater than that of air, ranging from 3·5 in the case of phosgene to 7·2 with Lewisite (v. Table I). Relative lightness was, incidentally, one of the chief reasons why hydrocyanic acid (relative vapour density 0·94) did not prove satisfactory when used in shell during World War I.

Freezing Point is not, in general, a very important factor, most of the war gases remaining liquid down to temperatures well below those likely to be met with under normal conditions. Mustard gas, however, has a relatively high freezing point (14·4°C.) and if used in a pure form on a cold day would probably freeze in the weapon, with possible introduction of difficulties in connection with ballistics and dispersion. In practice, therefore, mustard gas is generally mixed with some 15–20 per cent. of inert diluent such as carbon tetrachloride or chlorobenzene, or with a similar amount of some other substance having vesicant properties, to depress its freezing point to below 5°C., and so preclude freezing under normal conditions. Certain other gases, e.g., BBC (F.P. 25·5°C.) have to be similarly treated.

In connection with freezing point, also, reference must be made to the war "gases" which are really solids, such as CN (M.P. 58°C.), and the arsenical nose irritants (M.P. ranging from ca. 32 to 195°C.). The latter substances, in particular, have very low vapour pressures

CHAPTER II

The War Gases: Physical and Chemical Properties

5. Nerve Gases

The term "nerve gas" is applied to a number of organic phosphorous compounds, for the most part derivatives of cyano- or fluoro-phosphoric acid, which produce the symptoms briefly referred to in para. 2. The first compounds described as causing such symptoms were prepared in 1932, and certain of the less toxic materials of this type, notably di-isopropyl fluorophosphate (DFP), have since been intensively investigated as possible therapeutic agents. The more toxic members of the group were discovered in Germany during World War II, and two of them, conveniently referred to here by their German code names, Tabun and Sarin, were developed in that country as potential war gases. The very high toxicity of these gases, which is several times greater than that of previously known agents, and their extremely insidious nature—they have no irritant action and are practically undetectable by smell at concentrations which will in a matter of minutes produce incapacitation or death—make them very suited to employment for their morale effect against untrained persons. In this connection, it must be borne in mind that although a well-fitting respirator affords complete protection of the eyes and lungs against the vapours of these, as of the older war gases, the fitting and testing of respirators for leaks has become of far more critical importance since the advent of the nerve gases, since concentrations of gas which would previously have been without significant effect, may, with these new agents, cause serious symptoms to develop.

(i) *Tabun*

Tabun was the first of the really toxic nerve gases to be discovered, and considerable quantities of it were manufactured and filled into weapons in Germany during World War II. Although its lower volatility and lesser toxicity place it at a disadvantage compared with Sarin (see (ii)) the relative ease and cheapness of its production might encourage its use in preference to the latter.

Tabun when pure is a colourless mobile liquid of D.1.08, having a faint fruity odour, which can be detected under favourable conditions at fairly low concentrations. It can only be frozen with great difficulty (FP ca. – 50°C.) and boils at 246°C. with extensive decomposition (120°C./10mm.). It has a vapour pressure at ordinary temperatures of the same order as that of mustard gas. In the weapon charging used in Germany, the Tabun was mixed with 20 per cent. chlorobenzene, apparently in an attempt to increase the density of the charging for ballistic reasons, though the admixture also has the effect of masking the odour of the gas.

Tabun is a derivative of cyano-phosphoric acid, and is readily and completely soluble in water, giving a solution of high toxicity. Hydrolysis is slow, but is accelerated by alkalis, cyanide ion being liberated. In acid solution, dimethylamine is also formed, the ultimate product in all cases being phosphoric acid. Tabun is readily soluble in organic solvents, oils and fats. Apart from the hydrolysis, it is a relatively unreactive substance, though it does react vigorously with bleaching powder and other chlorinating agents with the evolution of considerable heat and the formation of cyanogen chloride (toxic).

In common with other nerve gases Tabun can be detected at very low concentrations by use of the NG reagents in the Portable Vapour Detector (App. I).

(ii) *Sarin*

Sarin was first made in Germany as the result of intensive research into phosphorous chemistry following the discovery of Tabun, and plant for its large scale production was under construction in that country at the end of World War II.

Like Tabun it is a colourless mobile liquid slightly heavier than water (D. 1·10), but it is virtually odourless and is toxic at much lower concentrations. Like Tabun also, it can only be frozen with difficulty (FP – 57°C.), but it boils at a much lower temperature (147°C. with extensive decomposition, or 56°/16mm.), and has a considerably higher vapour pressure at ordinary temperatures (some twenty times that of Tabun).

Sarin is a derivative of fluoro-phosphoric acid, and is freely soluble in water, organic solvents, oils and fats. It is hydrolysed slowly by water, and rapidly by alkalis, with liberation of fluoride ion and formation of non toxic phosphoric acid derivatives. It is otherwise chemically unreactive and derivatives are not easy to prepare.

The pure liquid does not attack steel, but it is extremely hygroscopic, and the water absorbed causes hydrolysis with the formation of acid which will exert a corrosive action.

6. Blister Gases

Mustard gas is the chief member of this group, and was the only one used to any extent during World War I, though the potentialities of lewisite and other dichlorarsines were being actively investigated when that war ended. Since then, the powerful new nitrogen mustard gases have been discovered, and although these were not employed in the field during World War II, preparation was made for their production by several of the belligerent countries. As a group, the blister gases exhibit considerable variation in physical and chemical properties, the dichlorarsine type being, in general, less persistent and less stable than mustard gas, or the nitrogen mustard gases, but they all possess the common characteristic of being able to penetrate into and destroy all living tissues with which they come into contact.

(i) *Mustard Gas*

Mustard Gas (H) (2·2′ dichlorodiethyl sulphide; $S(CH_2CH_2Cl)_2$) was known to the French as Yperite, since first used by the Germans

at Ypres on July 12th, 1917; and to the Germans as Senfgas, or Lost, the latter an anagram from initial letters of Lommel and Steinkopf, who advocated its use to the German Command.

Mustard gas when pure is a colourless oily liquid of D 1.28, having a faint leek-like odour. It freezes at 14·4°C. (with tendency to supercool) to long needles, and boils at 217°C. with decomposition (107°C./15 mm.). It has a low vapour pressure (0·072 mm. at 20°C.) and is accordingly very persistent. The technical product, usually containing 15–20 per cent. of carbon tetrachloride or chlorobenzene, is a brown or black oil, of variable F.P. (ca. 5°C.), having a characteristic odour described as resembling that of mustard, garlic, horseradish, etc.

It is very sparingly soluble in water (ca. 0·06 per cent. at ordinary temperature), in which it sinks, and is slowly hydrolysed by it to give harmless water-soluble products (thiodiglycol and hydrochloric acid), the hydrolysis being accelerated by heat or the presence of alkalis. It is soluble in most organic solvents, and in animal and vegetable oils, though not so soluble in mineral oils; it is absorbed by rubber, and penetrates into all porous materials, textiles, leather, wood, stone, etc.

It is a comparatively stable compound. Like all organic sulphides it possesses reducing properties, and on oxidation yields the corresponding sulphoxide (m.p. 109–110°C.) and sulphone (m.p. 56–57°C.) both of which are water soluble. The former is physiologically inert, but the latter possesses to some extent the vesicant characteristics of the parent sulphide.

Mustard gas is readily chlorinated to inert substitution products, and its chlorine atoms are relatively reactive, being replaceable by treatment with potassium iodide, sodium sulphide, etc. The pure liquid does not attack metals under ordinary conditions, but the technical product usually contains free hydrochloric acid and has a marked corrosive action on iron and steel.

(ii) *Lewisite*

Lewisite (American M-1) (2-chlorovinyl dichlorarsine: $ClCH=CH.AsCl_2$) was developed as a war gas by the Americans towards the end of World War I, though never actually tried out in the field, and derives its name from the American Col. Lee-Lewis. It was termed the "Dew of Death", and claimed to embody the aggressive qualities of the asphyxiants, the irritant characteristics of the tear and nose irritant gases, and the universal action on all tissues of the blister gases. However, these advantages over mustard gas are to some extent offset by the rapidity with which Lewisite hydrolyses in a damp climate.

Pure lewisite is a colourless, oily, and very heavy liquid, having B.P. 190°C. (decomp.) and F.P. ca. – 5°C. (considerable supercooling). It has a vapour pressure of 0·4 mm. at 20°C. and is therefore less persistent than mustard gas. The vapour of the pure compound has only a slight odour, but is markedly irritant to the eyes and nose. The liquid tends to turn blue-black in light. The technical product, which is usually black, has an intolerable geranium-like odour, perceptible in great dilution.

Lewisite is readily soluble in organic solvents and in oils and fats. It is rapidly hydrolysed by water to give the oxide, $ClCH=CH.AsO$,

which, although somewhat vesicant for direct contact, is much less dangerous than lewisite by reason of its non-volatility and sparing solubility in water and other solvents. A similar hydrolysis takes place in the presence of ammonium hydroxide, but with caustic alkalis the molecule breaks down, with evolution of acetylene.

Lewisite is a very reactive compound, being readily oxidised and chlorinated; and the two chlorine atoms attached to the arsenic are replaceable by treatment with potassium iodide, hydrogen sulphide, etc. It slowly decomposes in contact with iron, but does not appreciably attack steel.

Its action on the skin differs from that of mustard gas in that the liquid "stings", and the irritation develops more rapidly.

Certain other dichlorarsines, including ethyldichlorarsine ($C_2H_5AsCl_2$. B.P. 155°C.) and methyldichlorarsine (CH_3AsCl_2. B.P. 133°C.) have been considered as vesicants, but although their volatility and stability is higher than that of lewisite which they otherwise resemble chemically, their toxicity is lower.

It should be pointed out that the danger of serious eye and skin injury resulting from the use of the arsenical vesicants has been greatly reduced by the discovery of the therapeutic value of 2, 3-dimercapto-propanol (British Anti-Lewisite, BAL) in cases of arsenical poisoning. BAL combines with arsenical compounds reducing their toxicity very considerably and under competent medical supervision great success can be achieved in the prevention and healing of lesions caused by such substances.

(iii) *Nitrogen Mustard Gases*

The nitrogen mustard gases are members of the series of tertiary 2, 2′-dichlorodialkylamines of the general formula R N $(CH_2CH_2Cl)_2$ where R is an alkyl, haloalkyl or aryl group. The first compound of this type to be described was tris (2-chloroethyl) amine (HN-3, German "Stickstofflost"), which was prepared in 1935. Although having a lower toxicity than mustard gas it appeared to possess certain advantages over that compound, and immediately prior to World War II it was in production on a plant scale in several continental countries. Subsequent research disclosed other compounds of similar toxicity, of which only bis (2-chloroethyl) methylamine (HN-2) seemed to show any superiority over HN-3.

HN-3 is a colourless, almost odourless liquid, FP. +3·7°C., B.P. 120°C./5·5 mm. and has a very low vapour pressure (0·0071 mm./20°C.). As a vesicant it is considerably less powerful than H, but it has a more damaging effect on the eyes. The vapour causes no immediate irritation, and indeed a dangerous concentration may not be detected by the senses. Some time elapses before any effect is noticed, but the resulting eye injury may be of long duration. Because of the low vapour pressure of HN-3, however, the full effect of these eye-injurant properties is difficult to achieve under field conditions. In this respect HN-2 (F.P. – 60 to – 65°C., B.P. 59°C./2 mm. vapour pressure 0·301 mm./20°C.) is superior to HN-3.

Both HN-2 and HN-3 are typical tertiary amines, forming quarternary salts with acids or alkyl iodides. The hydrochlorides are white solids,

TABLE I—PHYSICAL PROPERTIES OF THE WAR GASES

War Gas	Mol. Wt.	Freezing Point	Boiling Point	Density	Vapour Density	Vapour Pressure	" Volatility "	" Persistence"*
		° C.	° C./760 mm.	D_4^{20} (g/c.c.)	N.T.P. (air=1)	20° C. (mm. Hg.)	=Saturation conc. (mg/l) at 20° C.	At 20° C. (approx. time for evaporation, relative to water at 15° C.)
Nerve Gases								
Tabun . . .	162	− 50	246 (calc.)	1·08	5·6	0·05	0·4	86
Sarin . . .	140	− 57	147 (dec.)	1·10	4·9	1·57	12·1	2·95
Blister Gases								
Mustard Gas .	159	+ 14·4	217 (dec.)	1·28	5·4	0·072	0·63	58
Lewisite . .	207·3	− 2·4	190 (dec.)	1·89	7·2	0·4	4·5	9·5
HN–2 . . .	156	− 60–65	193 (calc.) (59/2 mm.)†	1·13	5·4	0·301	2·6	14·5
HN–3 . . .	204·5	− 3·7	256 (calc.) (120/5·5 mm.)†	1·24	7·1	0·0071	0·08	540
Choking Gases								
Phosgene . .	98·9	−118	+ 8	(1·37)	3·5	1185	Gas	N.P. gas
Diphosgene . .	197·9	− 57	128	1·65	6·9	10·3	112	0·38
Chloropicrin. .	164·5	− 69	112	1·66	5·7	18·3	165	0·23
Tear Gases								
BBC . . .	196	+ 25·4	242 (dec.)	1·52	6·8	0·012	0·13	325
CN (CAP) . .	154·5	+ 55	247	1·32	5·3	0·004	—	N.P. Cloud

TABLE I—PHYSICAL PROPERTIES OF THE WAR GASES—*continued*

War Gas	Mol. Wt.	Freezing Point	Boiling Point	Density	Vapour Density	Vapour Pressure	" Volatility "	" Persistence"*
		° C.	° C./760 mm.	D_4^{20} (g/c.c.)	N.T.P. (air=1)	20° C. (mm. Hg.)	=Saturation conc. (mg/l) at 20° C.	At 20° C. (approx. time for evaporation, relative to water at 15° C.)
Nose Gases								
DA	264·5	+ 38	333 (dec.)	1·4	—	0·0005	—	N.P. Cloud
DC	255	+ 33	377 (calc.)	1·45	—	0·0002	—	N.P. Cloud
DM	277·5	+195	410 (calc.)	1·65	—	2×10^{-13}	—	N.P. Cloud
Other Gases								
Hydrocyanic Acid	27	− 15	26·5	0·7	0·94	610	901	0·02
Arsine	78	−116	− 62	(1·64)	2·7	15 atm.	Gas	N.P. gas
Chlorine trifluoride	92·5	− 83	12	(1·82)	3·2	1010	Gas	N.P. gas

* As a rough guide, the unit of the quoted persistence values may be taken as approximately one hour in dry weather on open even ground.

† Polymerise explosively on distillation at atmospheric pressure.

TABLE II—ODOUR AND IRRITANT EFFECTS OF THE WAR GASES

War Gas	Odour		Irritant Effects		Intolerable Concentration	Habers "Mortality Product"
	Character	Minimum perceptible concentration mg./m³	Nature	Threshold of action mg./m³	1–2 min. exposure mg./m³	= conc. (mg./m³)x duration of exposure (min.) for fatal effects
Nerve Gases						
Tabun	Faint fruity	1–2	None	—	—	Some ten times as toxic as phosgene
Sarin	Not perceptible	—	None	—	—	
Blister Gases						
Mustard Gas	Garlic, horse-radish, onions, mustard	pure 0·3 crude 0·03	No immediate effects	—	—	1,500
Lewisite	Geraniums	Irritates almost as soon as odour is perceived	Nose and throat irritation	0·5–1	1	1,500
HN–2	Faint fishy	13–15	No immediate effects	—	—	3,000
HN–3	Almost odourless	—	No immediate effects	—	—	1,500
Choking Gases						
Phosgene	Musty hay	1–2	Eye and throat irritation	15–20	40	3,200
Diphosgene	Like phosgene	1–2	Eye and throat irritation	15–20	40	3,200
Chloropicrin	Sweetish and penetrating	5–10	Eye irritation; lachrymation Throat irritation	5–10 40	50–100	6,700
Tear Gases						
BBC	Sour fruit	Irritate before odour is perceived	Lachrymation	0·04	30	15,000
CN (CAP)	Aromatic, apple blossom		Lachrymation	0·05	4·5	>20,000

TABLE II—ODOUR AND IRRITANT EFFECTS OF THE WAR GASES—*continued*

War Gas	Odour		Irritant Effects		Intolerable Concentration	Habers "Mortality Product"
	Character	Minimum perceptible concentration mg./m³	Nature	Threshold of action mg./m³	1–2 min. exposure mg./m³	= conc. (mg./m³)x duration of exposure (min.) for fatal effects
Nose Gases						
DA . . .	Faint, aromatic	Irritate almost as soon as ordour is perceived	Nose and throat irritation	0·1	1–2	4,000
DC . . .	Faint, bitter almonds		Nose and throat irritation	0·05	0·25	4,000
DM. . . .	Faint, aromatic amine		Nose and throat irritation	0·05–0·1	0·4	4,000
Other Gases						
Hydrocyanic acid .	Bitter almonds	5–10	None	—	—	1,000–4,000
Arsine . . .	Acetylene-like	50–100	None	—	—	5,000–10,000
Chlorine trifluoride	Penetrating "halogen" or phosgene	ca 10	Nose and throat irritation	Not determined		>20,000

Note: Owing to the very large variations of personal idiosyncrasy, the above figures must be regarded as approximate only.

TABLE III—CHEMICAL PROPERTIES OF THE WAR GASES

War Gas	Behaviour to Water	Products of Hydrolysis		Neutralising Agents
		With Water	With Alkali	
Nerve Gases				
Tabun	Soluble, slowly hydrolysed	HCN, H_3PO_4, etc.	As with water	Alkali; sodium bicarbonate and hydrogen peroxide.
Sarin	Soluble, slowly hydrolysed	HF and the corresponding half ester, $CH_3PO(OR)OH$ (non-toxic)	As with water, but much more rapid. Final product $CH_3PO(OK)_2$	
Blister Gases				
Mustard Gas	Slowly hydrolysed (rapidly on boiling)	HC_1 and thiodiglycol (non-toxic)	As with water. (With conc. alc. KOH gives foul smell of divinyl sulphide.	Oxidising agents (permanganate, nitric acid, etc. Chlorine, bleaching powder chloramine-T. Aqueous sodium sulphide (slow).
Lewisite	Rapidly hydrolysed	HC_1 and ClCH=CHAsO (toxic, sparingly soluble)	Decomposed into C_2H_2, KCl and K_3ASO_3 (toxic)	Alkali, bleaching powder, hydrogen peroxide.
HN–2	Slowly hydrolysed	Non-toxic glycol by way of a series of toxic intermediates	As with water, but more rapid	Bleaching powder; sodium bisulphate, alcoholic alkali.
HN–3	Slowly hydrolysed			
Choking Gases				
Phosgene	Rapidly hydrolysed	HC_1 and CO_1	As with water	Alkali; alkaline phenates: amines (particularly hexamine).
Diphosgene	Rapidly hydrolysed			
Chloropicrin	Stable	—	With KOEt gives KCl, KNO_2 and $C(OEt)_4$	Alcoholic potash; alkali polysulphide; aqueous-alcoholic sodium sulphite.

TABLE III—CHEMICAL PROPERTIES OF THE WAR GASES—*continued*

War Gas	Behaviour to Water	Products of Hydrolysis		Neutralising Agents
		With Water	With Alkali	
Tear Gases				
BBC	Stable	—	With alc. KOH gives KBr and $(PhC(CN){=})_2$	Alcoholic alkali
CN (CAP)	Stable	—	KCl and $PhCOCH_2OH$	Alkali; sodium thiosulphate.
Nose Gases				
DA	Slowly hydrolysed	As with alkali	KCl and $(Ph_2As)_2O$ (toxic)	Alkali; chlorine; oxidising agents (peroxide); chloramine T; iodine in presence of sodium bicarbonate.
DC	Stable	—	KCN and $(Ph_2As)_2O$ (toxic)	
DM	Stable	—	KCl and corresponding oxide (toxic)	
Other Gases				
Hydrocyanic acid	Miscible; slowly decomposed.	Ammonium formate and brown polymeric products	KCN (toxic)	Alkali.
Arsine	Slightly soluble: slowly decomposed	Deposits arsenic, some oxidation to arsenite (toxic)	—	Oxidising agents.
Chlorine trifluoride	Explodes violently	HF, HCl, F_2O (toxic), etc.	As with water	Alkali, ammonia, water (fine spray)

PORTABLE DOSERATE METER - PREPARATION FOR USE

PDRM 82D
DECONTAMINATION METER

The unit is supplied with battery cap, neck strap, lanyard, probe, probe holder and audible indicator. (For fitting instructions see both sides of this card).

The three cells required are not packed with the unit.
The recommended cell type conforms to BS397 size LR14 (type C)
(Commercial cells Duracell type MN1400 or equivalent of 1.5V rating may be used).

Alkaline batteries should be used

The batteries should be removed for storage.

NOTE Lithium batteries should not be used as the higher voltage may damage the unit.

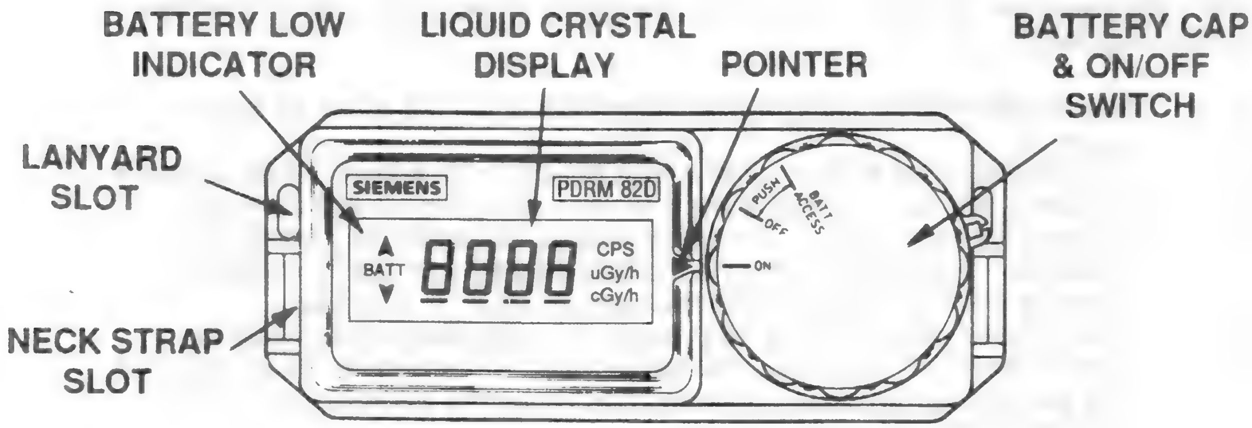


FIG 1

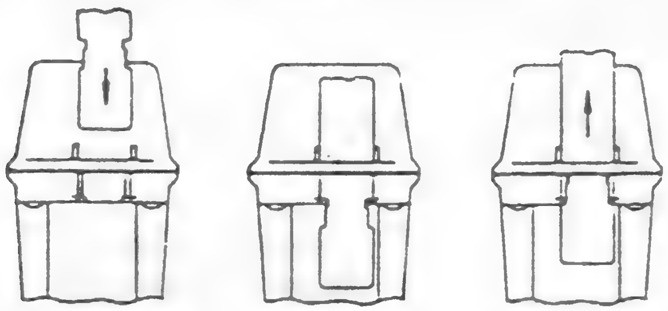


FIG 2a FIG 2b FIG 2c

Fitting the Neck Strap
Insert one end of strap through the slot in the case as in Fig. 2a
Push the narrow section of the strap into lower section of moulding Fig. 2b
With the strap held against the moulding pull the strap back to 'lock' it into position Fig. 2c
Two attachment positions are provided at each end of the strap for adjustment of length.

TO PREPARE THE UNIT FOR OPERATION

Fit three cells in the housing with positive (+) terminal up (towards the cap end).

Place the battery cap with BATT ACCESS marking adjacent to the pointer, press the cap down fully and twist clockwise to the OFF position.

Rotate switch to ON position and observe that all display segments, battery low indicator, cps, uGy/h and cGy/h (fig. 1) function for a short period followed by 'TEST'. During 'TEST' the audible indicator (if fitted) will produce a burst of sound.

After 2 to approx. 10 seconds the unit will display 0 and one of the engineering units. If there is significant radiation level present that level will be displayed.

Four segments will flash alternately indicating that the unit is operating.

In the event of a failure the word 'FAIL' will be displayed in place of the normal digits. If the 'FAIL' display does not clear within ONE minute to .0 the faulty unit should be discarded or returned for repair.

NOTE 1 — The probe may be hung on the probe holder on the strap as shown in figure 3.

NOTE 2 — If the display fails to work check that the cells have been fitted correctly as stated above incorrect fitting will not cause permanent damage.

NOTE 3 — If at any time the 'BATT' indication shows, the batteries should be replaced. Prolonged use of the instrument with the 'BATT' indication showing will lead to a progressive deterioration in accuracy.

NOTE 4 — The audible indicator may be threaded on the strap and should be connected to the socket on the bottom of the instrument when required. The protective cap should be replaced when the audible indicator is disconnected.

WARNING — The audible sounder can produce dangerously high noise levels. The noise level can be reduced by rotating the muffler to close the holes in the end of the sounder.

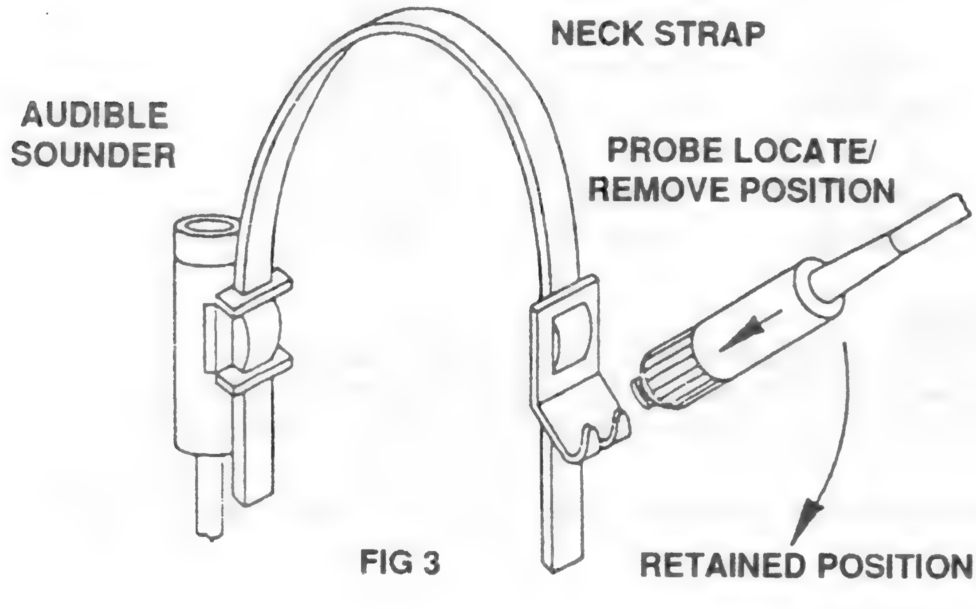


FIG 3

CERTIFICATE OF CALIBRATION

OF A RADIATION PROTECTION INSTRUMENT
ISSUED BY DSTL NUCLEONIC INSTRUMENT SERVICES
PERIODIC TEST **NO ADJUSTMENTS REQUIRED**
DATE OF ISSUE 20-Jul-10 CERTIFICATE NUMBER 125856.1

UKAS CALIBRATION
0477

dstl **Nucleonic Instrument Services.**
Institute of Naval Medicine
Alverstoke, Gosport, Hants. PO12 2DL
Telephone (023) 92768171 Fax (023) 92768150

Approved Signatory

M. Sa

Mr M Sanders

ADMINISTRATION

Calibration Date	20-Jul-10	Receipt Date	13-Jul-10	Test Result	**PASS**
Customer Name	CBRN IPT POOL	Customer Address:	BRISTOL BS34 8JH		
Instrument Type	PDRM 82D	Instrument Serial Number	00122512		
Probe Type	PDRM82D EXT PROBE	Probe Serial Number	N/A		

RESULTS

ISOTOPE	RANGE	AIR KERMA RATE	OBSERVED READING (μGyh^{-1})	CALIBRATION FACTOR
Bg	0 - 9999 μGyh^{-1}	N/A	0.0	N/A
^{137}Cs	0 - 9999 μGyh^{-1}	5000 μGyh^{-1}	4923.7	1.02 ± 4%
^{137}Cs	0 - 9999 μGyh^{-1}	500 μGyh^{-1}	494.5	1.01 ± 4%
^{137}Cs	0 - 9999 μGyh^{-1}	100 μGyh^{-1}	101.0	0.99 ± 5%
^{137}Cs	0 - 9999 μGyh^{-1}	25 μGyh^{-1}	24.8	1.01 ± 7%
^{137}Cs	0 - 9999 μGyh^{-1}	10 μGyh^{-1}	10.0	1 ± 10%
^{137}Cs	0 - 9999 μGyh^{-1}	5 μGyh^{-1}	5.0	1 ± 19%
^{241}Am	0 - 9999 μGyh^{-1}	25 μGyh^{-1}	27.2	0.92 ± 10%

Note: Observed readings are all minus background reading.

POLAR RESPONSE TEST	POLAR RESPONSE TEST NOT REQUIRED

The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95%
The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY NO. 0477

Certificate Number
125856.1

COMMENTS

1. Visual inspection of the instrument for damage and wear, battery / battery compartment checks and appropriate mechanical and electrical checks were carried out prior to calibration. The condition of the instrument was found to be satisfactory.

2. Calibration Procedure: The probe was placed horizontally across the beam and was exposed to known Air Kerma dose rates in Cs-137 and Am -241 gamma-ray beams. The instrument readings are quoted in μGyh^{-1}.

3. No temperature or pressure corrections were carried out for this instrument.

4. An Overload test was performed on this instrument. The highest dose rate applied to the instrument during this calibration was 110 $mGyh^{-1}$ > 11 times FSD for this type of instrument.

5. The response of this instrument required no adjustment to bring the linearity to within +/- 30% for Cs-137 or +/- 30% for the low energy Am-241 test.

PDRM 82D.xls Ver 02

NOTES:

1 The tests were carried out by or under the supervision of a Qualified Person and satisfy the requirements of the Ionising Radiations Regulations. They were carried out in accordance with the guidance given in the Good Practice Guide No. 14 "The Examination, Testing & Calibration of Portable Radiation Protection Instruments" published by the National Physical

2 The overall uncertainty of the dose rates for Cs-137 & Co-60 is ± 3%, and for Am-241 is ± 5%. The overall uncertainty was calculated in accordance with M3003 "The Expression of Uncertainty and Confidence in Measurement". Full details on the uncertainty treatment are available on request. This does not include 2% for converting air kerma to dose equivalent detailed in ISO 4037 (3) para 4.1.2.

3 A minimum of 6 readings are noted and the mean taken to give the observed reading. The result sheet shows these readings.

4 Where appropriate, conversion from air kerma to ambient dose equivalent (H*(10)), was carried out using the factors 1.2 for Cs-137 and 1.74 for Am-241 as detailed in ISO 4037 (3).

5 The photon air kerma and ambient dose equivalent rates used in this test were measured using a secondary standard measuring instrument whose calibration is traceable to national standards. All ancillary equipment (rulers, timers, barometers, thermometers etc.) used are also traceable to national standards.

6 In accordance with the Ionising Radiations Regulations 1999, the instrument should be adequately tested and examined at appropriate intervals. The Approved code of Practice recommends that monitoring equipment should be tested and thoroughly examined at least once a year.

QC
11
PASS

00122512

[redacted] GAMMA

F P F P

The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a level of confidence of approximately 95%
The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CUSTOMER	CBRN IPT POOL		CALIBRATION LOG No	125856.1		
ADDRESS	BRISTOL BS34 8JH		DATE PRINTED	20-Jul-10		
CALIBRATION DATE	20-Jul-10	RECEIPT DATE	13-Jul-10	TEMPERATURE	24.2	°C
INSTRUMENT TYPE	PDRM 82D	SERIAL No	00122512	PRESSURE	1011.2	mb
PROBE TYPE	82D EXT PROBE	SERIAL No	N/A			
BATTERY CHECK OKAY	YES	SET ZERO OKAY	N/A	MECHANICAL INTEGRITY OKAY	YES	

		BEFORE								POLAR RESPONSE	
										+90°	-90°
ISOTOPE	Bg	Cs 137	Cs 137						Am 241	Am-241	
INSTRUMENT READING	μGyh^{-1}	5000 μGyh^{-1}	5000 μGyh^{-1}	500 μGyh^{-1}	100 μGyh^{-1}	25 μGyh^{-1}	10 μGyh^{-1}	5 μGyh^{-1}	25 μGyh^{-1}	25 µGyh-1	
READING 1	0		4933	488	100	23	11	5	25		
READING 2	0		4941	496	96	25	8	6	26		
READING 3	0		4946	487	100	23	10	3	27		
READING 4	0		4881	488	102	25	11	5	28		
READING 5	0		4935	500	105	27	10	6	30		
READING 6	0		4906	508	103	26	10	5	27		
MEAN READING	0.00	0.0	4923.67	494.50	101.00	24.83	10.00	5.00	27.17	0.00	0.00
READING - B/G		0.0	4923.67	494.50	101.00	24.83	10.00	5.00	27.17	0.00	0.00
±30% OF TEST TYPE DATA			PASS	PASS	PASS	PASS	PASS	PASS	PASS	FAIL	FAIL
OVERALL UNCERTAINTY %	#DIV/0!		3.63	3.87	4.39	6.38	9.64	18.25	9.24		

COMMENTS

OVERLOAD TESTS PERFORMED YES 110 $mGyh^{-1}$ > 10 TIMES FSD

SOUNDER RESPONDED WHEN EXPOSED TO RADIATION YES

Exposures were AIR KERMA

OPERATORS NAME: R J Goble **APPROVED SIGNATORY NAME** M Sanders

OPERATORS SIGNATURE: **RESULTS CHECKED (QP SIGNATURE):** M. Scef

SUPERVISED BY: M Sanders PDRM 82D.xls Ver 02

JTB. Bennett
S. Threadingham
R. Truman
M. Sanders

CERTIFICATE OF CALIBRATION
FOR GAMMA DOSE RATE MONITOR

ISSUED BY THE RADIATION MONITORING INSTRUMENT MAINTENANCE CENTRE (RMIMC), RAFARMSUPU.

CERTIFICATE NO: MD3/0756/270799

ROYAL AIR FORCE ARMAMENT SUPPORT UNIT
Royal Air Force Wittering
Peterborough
Cambridgeshire PE8 6HB
Telephone Stamford (PSTN 01780) 783838 (RAFTN 95351) Ext. 3145

Customer Name	:	TMEC
Customer Address	:	RAF LINTON ON OUSE

Instrument Type	:	**METER DOSERATE No 3**	Serial No	:	0756
Sect Ref/NSN	:	6Z (6665 99) 7814694	Type of Test	:	Annual (Category 2)
Date of Calibration	:	27 July 1999	Result of Test	:	**PASS**

Type of Test	Nuclide	Source Serial Number	Air KERMA Doserate	Observed Reading
Linearity	^{137}Cs	661	1 $cGyh^{-1}$	1.1 $cGyh^{-1}$
Linearity	^{137}Cs	661	2 $cGyh^{-1}$	2.1 $cGyh^{-1}$
Linearity	^{137}Cs	159	10 $cGyh^{-1}$	10 $cGyh^{-1}$
Linearity	^{137}Cs	159	20 $cGyh^{-1}$	21 $cGyh^{-1}$

***NOTE* No Overload, Energy Response or Upper Range linearity tests were carried out on this instrument**

This certificate contains the approved particulars for a record of tests required in pursuance of Regulation 24 of The Ionising Radiation Regulations 1985 and complies with the test specification recommended in HSE(G)49.

The response of this instrument was within ±20% of the dose rates to which it was exposed.

The overall uncertainty of radiological measurements carried out in the Gamma Calibration Facility have been calculated to be: 5.43% at 95% CL. The radiation fields used are traceable to Primary Standards at the National Physical Laboratory.

Operator: J/T RHODEN Signature:

Qualified Person: SGT PARKINSON Signature:

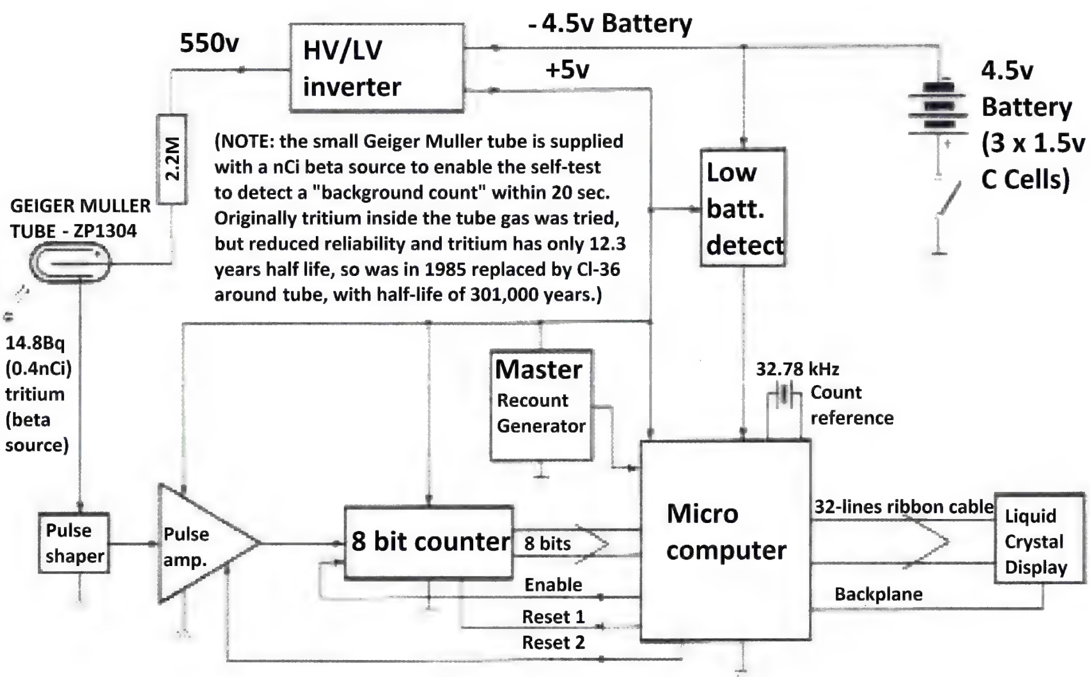
25 May 1983 UK Home Office Radiac Instruments Circular to Emergency Planning Officers
NOTE: original price of portable PDRM82 was £400 + VAT.

The Portable Dose Rate Meter - PDRM 82

For the past 30 years, the U.K. Civil Defence organisation has been equipped to monitor for radioactive fallout following a nuclear conflict. During the past 10 years maintenance and repair of the instruments has been made increasingly difficult because of obsolete components and the equipment is becoming generally less reliable. The British Government, in collaboration with the Ministry of Defence, specified a replacement unit and Plessey Controls won the contract to develop and manufacture 79,000 portable and 1,050 fixed post instruments.

The new specification requires the instrument to monitor for gamma radiation over the range 0.1 cGy/h to 300 cGy/h (1 cGy = 1 rad).

The unit is expected to operate in extreme conditions and in order to satisfy this requirement has been type tested to the most stringent of specifications. The tests performed include shock and vibration, temperature cycling, immersion, EMC and EMP, the latter being an electromagnetic pulse resulting from the detonation of a nuclear device. The instrument was required to have a long working lifetime with each set of batteries and a period of 400 hours of continuous operation can be expected with standard C cells at nominal dose rate.



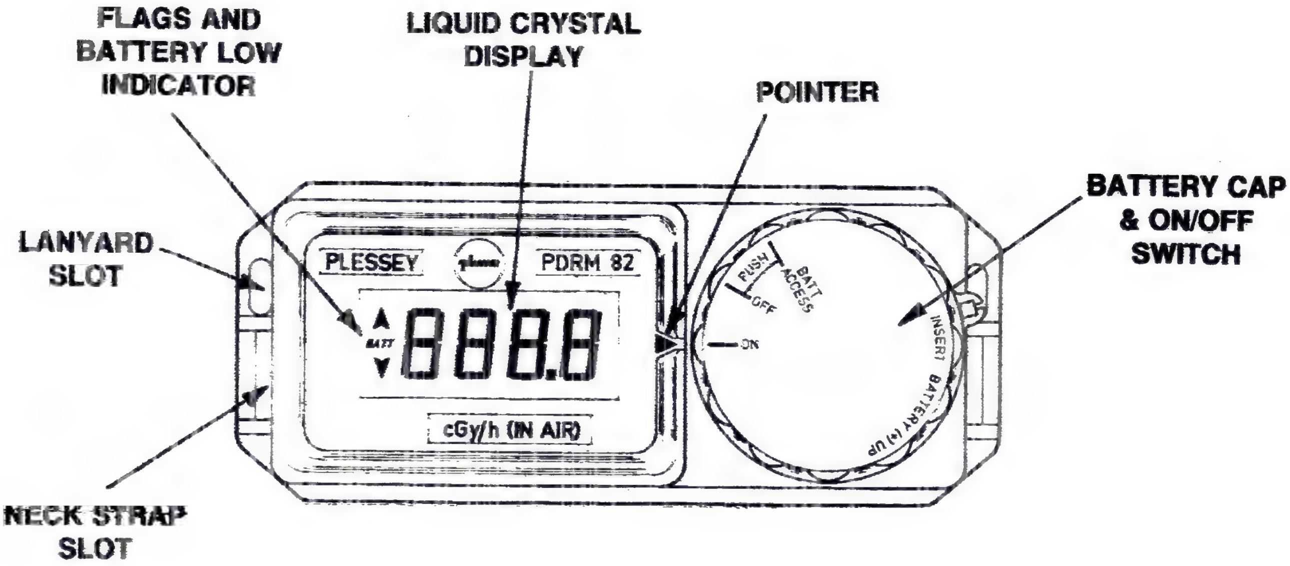
(SOURCE OF DIAGRAM: Civil Defence Operational Radiac Instruments, part S4.)

Block Diagram of the Portable Dose Rate Meter Circuit

G-M TUBE DEAD-TIME CORRECTIONS:
50,000 c/s = 292 cGy/hr
20,000 c/s = 75.3 cGy/hr
1000 c/s = 3.1 cGy/hr
100 c/s = 0.31 cGy/hr

ORIGINAL PDRM82 GEIGER MULLER TUBE, 7mm ZP1304, gives 340 (counts/sec)/(Cs137 R/hr)

The later PDRM82D for decontamination uses the more sensitive, 20 (c/s)/(mR/hr), Geiger Muller tube ZP1401 or energy compensated ZP1201



Immediately after switch-on the computer interrogates the electronic circuitry to establish the healthy state of the instrument. During this period the display reads 'TEST'. If a fault exists the LCD is programmed to display 'FAIL'. The function of the G.M. tube is continuously checked by the computer which monitors the background count due to an in-built nano-curie Beta source. This very small source is part of the G.M. tube assembly which includes compensation elements to ensure the correct response throughout the energy spectrum and in addition, corrects the G.M. tube's otherwise unacceptable polar response so that the unit is not directionally sensitive.

When the instrument is being used in an area where the contamination varies significantly, the LCD is made to display either an increasing or decreasing flag on the left side of the display window, if the dose rate varies by more than a preset number of cGy/h per counting period. This facilitates the location of hot-spots in the field or on equipment.

Another element of the LCD display indicates 'BATT' when the batteries need to be changed. There is typically 10 hours life left in the cells at the time when this display is first indicated.

The fixed post monitor is identical to the standard portable unit except for the detecting element which is remotely connected by a coaxial lead with a plug and socket onto the rear of the unit. This enables external conditions to be monitored from within a bunker as with the existing civil defence instruments.

The instrument incorporates components to BS9000 or CECC standards, which results in high reliability. As an example, at 25°C operated as a portable instrument, the calculated MTBF is 24,000 hours. Operating in a fixed position and not suffering the rough handling expected in field use, this figure increases to 90,000 hours. Since the instrument has been designed to meet the requirement of a long shelf life the probability of failure after 20 years storage is predicted to be at the very low rate of 4% or less.

The large number of instruments required by the Home Office has allowed mass-production techniques. This results in an inexpensive high performance instrument which is now available to all emergency monitoring organisations around the world.

3640/FDS/BEH/2
25.5.83.

NOTE: the original PDRM82 was produced by Plessey, but the decontamination meter PDRM82D was made by Siemens PLC from 1995: NATO item Z8/6665-99-193-6937.

RADIOLOGICAL DOSE RATE METERS

PDRM 82 & PDRM 82F

Radiation.

a) Nuclear.

Total dose accumulation of 1500cGy of gamma radiation at a dose rate no greater than 100cGy/h does not affect the instrument.

b) Electromagnetic Pulse (Nuclear).

Exposure to category B exoatmosphere EMP as defined in DEF STAN 07-55 Part 2, Section 5/1 Test E1. Equipment in operational condition during the test.

Electromagnetic susceptibility as defined in NWS 3 Class A.

Emission of Radio Frequency Interference as defined in NWS 3 Class A for frequencies above 150 KHz.

October 1982

Plessey Controls
Sopers Lane
Poole
Dorset
England BH17 7ER

The design technology used incorporates components mainly to BS 9000 or CECC standards which provides the instrument with a very high reliability. As an example at 25°C, operating in a mobile role, the calculated mean time between failure is 24,000 hours. Operating in a fixed position the figure increases to 90,000 hours. The instrument is designed for a 20 year storage period and the probability of failure during this period is predicted at less than 4% of the total units stored.

(a) Technical characteristics. PDRM 82 Portable Version.

Range:	0 to 300 cGy/h in 0.1 cGy/h increments. Between 300 cGy/h and 1500 cGy/h instrument displays 300 flashing.
Accuracy:	±20% of true dose rate, 0.1 cGy/h. (in air) in the range zero to 100 cGy/h. ±30% of true dose rate (in air). in the range 100 to 300 cGy/h.
Operating Temperature Range:	-10°C to + 45°C.
Energy Response:	0.3 MeV to 3 MeV within ± 20% (Ra 226). 80 KeV to 300 KeV within ± 40% (Ra 226)
Detector:	Halogen quenched Geiger Muller tube.
Indication:	Four digit 12mm high, liquid crystal wit additional indication features of direction change of doserate and battery low.
Power Supply:	Three international standard 1.5 volt C cells. (R14HP)
Case:	Waterproof moulded polycarbonate 3mm thick.
Size:	175mm x 135mm x 50mm.
Weight:	560 gms inclusive of batteries.
Carrying Support:	Adjustable neckstrap and waist steadying lanyard.

(b) Technical Characteristics. PDRM 82 F Fixed Version.

The characteristics and construction of the fixed post monitor are the same as for the portable version. The physical variations are as listed.

Case:	Moulded polycarbonate 3mm thick with screwed co-axial cable connector.

Military Shelters

TECHNICAL MANUAL

Marconi
Radar Systems

CONCLUSIONS

It is obvious that this whole subject of EMP protection has far reaching consequences for everyone.

From what has been said so far, it can be seen that a deliberate detonation of a nuclear weapon to maximise the EMP effect could and probably would occur in any future conflict. This could affect countries not even involved in the conflict itself.

The probable effects of EMP exposure would mean telephone communications would be knocked out in most, if not all parts of the country. Landline and repeater equipment would be destroyed and rendered useless. Radio communications would be impossible, VHF broadcast receivers and mobile VHF equipment would be severely damaged. HF transmitter and receiver units would be useless, especially the widely used broadband radio and radar equipment. Mains power supplies would also be damaged.

In essence then, electronic communication and power supplies would cease to exist once an exo-atmospheric blast which produces a significant EMP has taken place. It is popularly supposed that this would be a temporary situation, but this is not the case and wide spread and immediate destruction of equipment would occur, which would take extensive repairs to correct. It is a sensible precaution to protect strategically important systems. The Marconi shelter range offers a cost-effective way of doing it.

Shelter A.C. supply

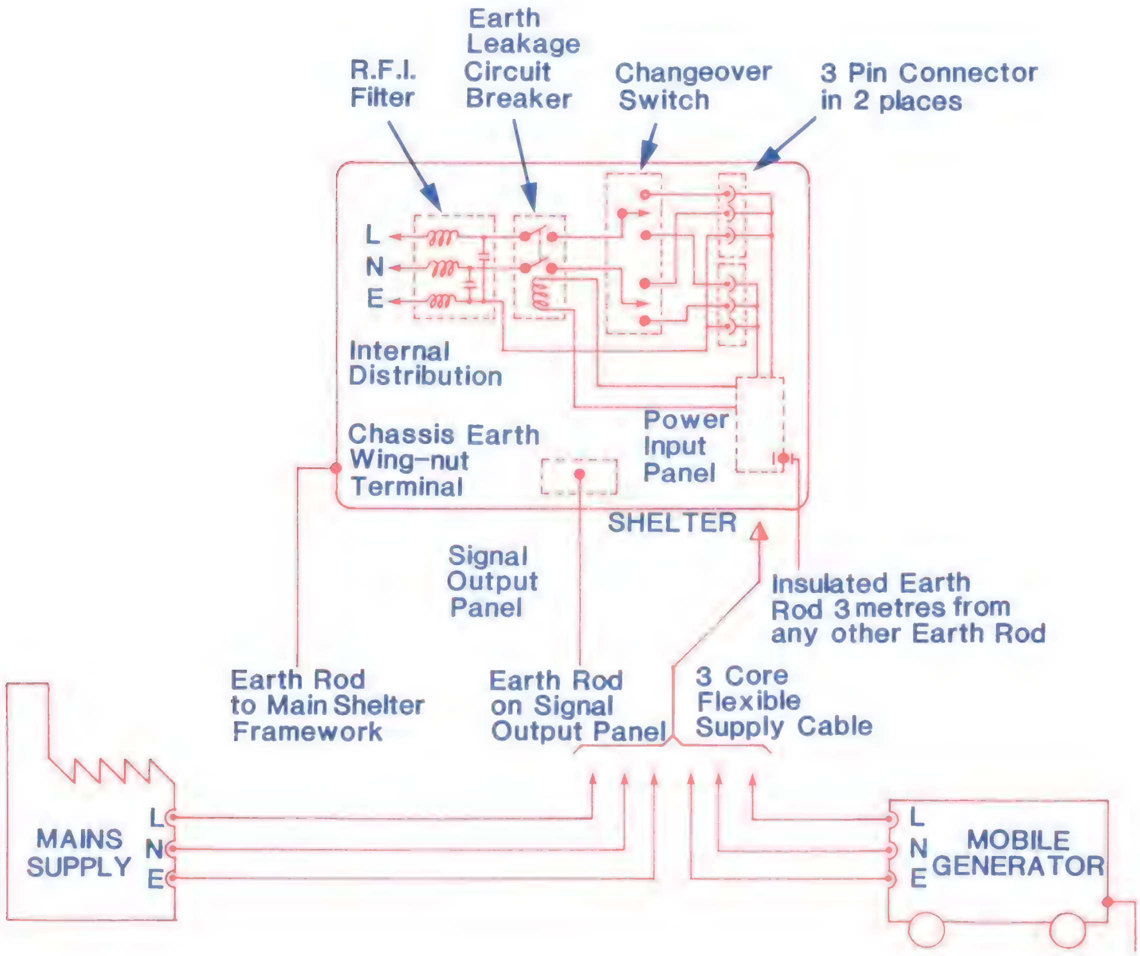


FIG.400

Shelter D.C. supply

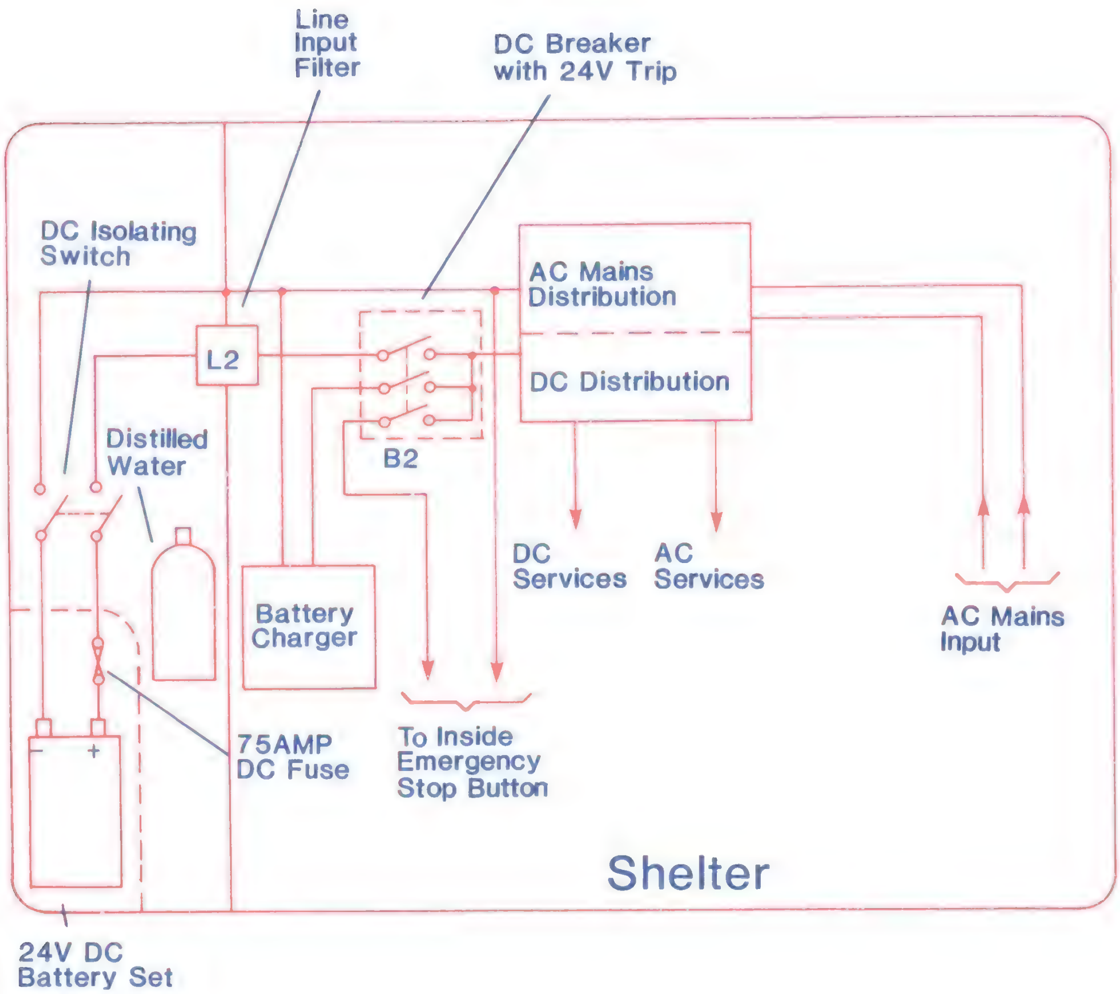
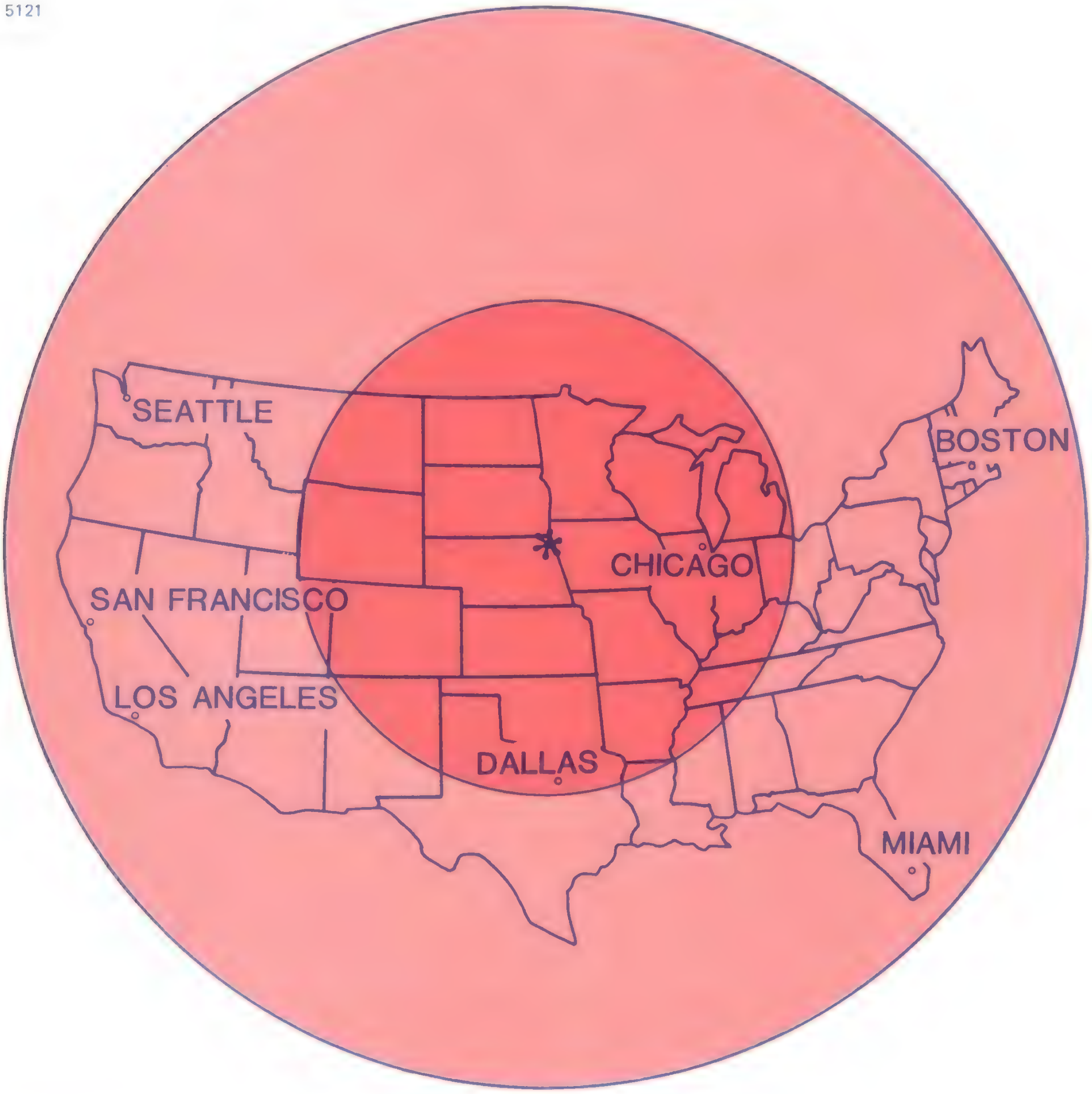


FIG. 410

E.M.P. blanket area for nuclear burst at 50 mile and 120 mile heights

5121



* POSITION OF NUCLEAR BLAST

INNER CIRCLE – COVERAGE IF DETONATED AT A HEIGHT OF 50 MILES

OUTER CIRCLE – COVERAGE IF DETONATED AT A HEIGHT OF 120 MILES

FIG. 560

One megaton burst over the North Sea

DETRIMENTAL DAMAGE TO EQUIPMENT

SERIOUS DAMAGE TO EQUIPMENT

FIG. 550

E.M.P. energy collectors

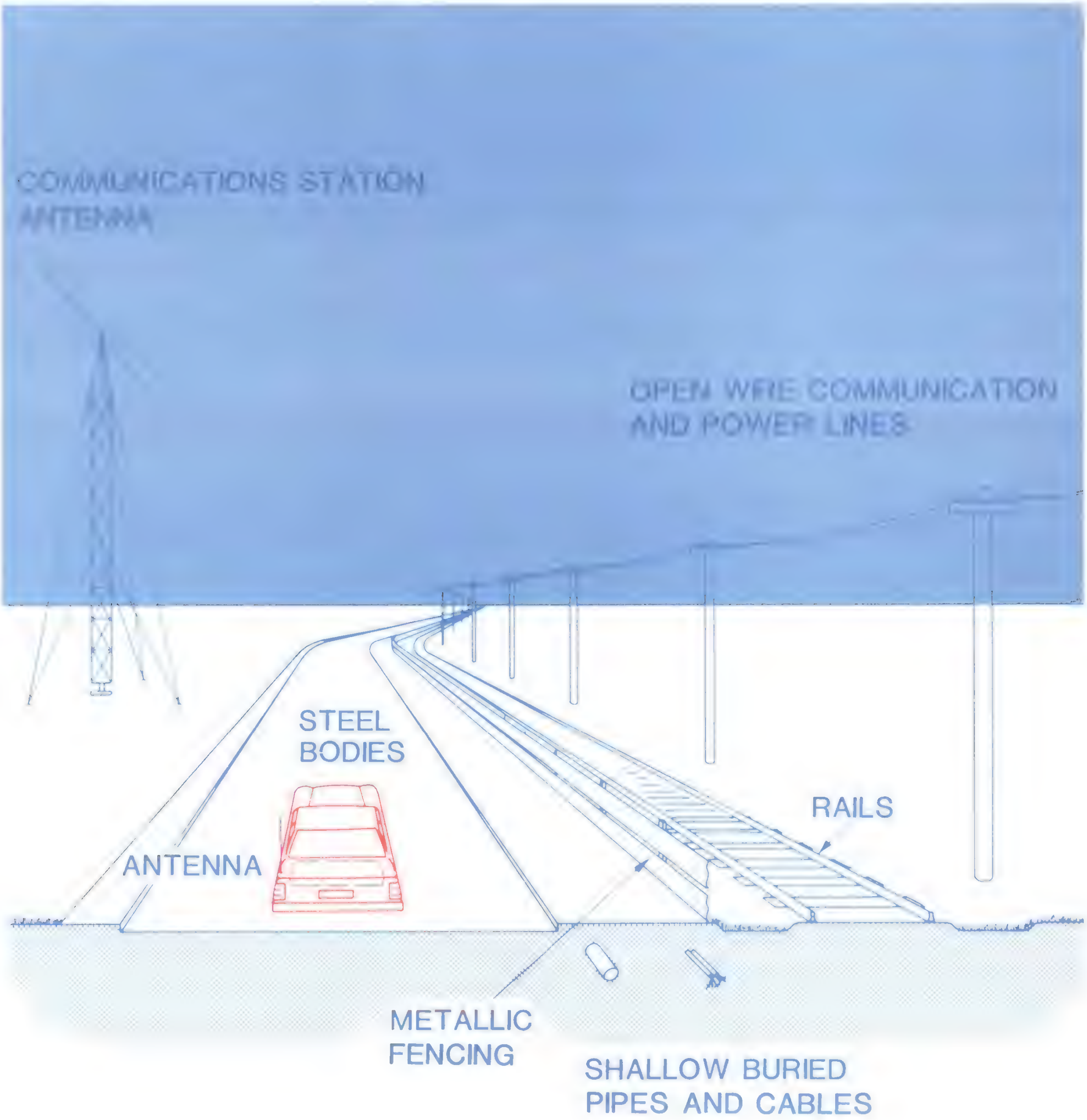


FIG. 590

Frequency spectrum comparison

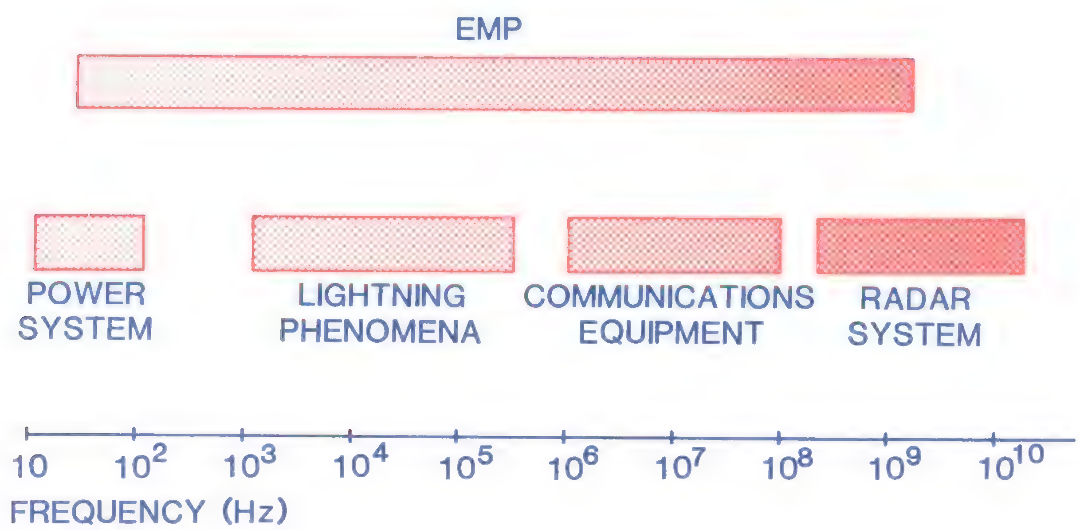


FIG. 570

Field strength produced by one megaton ground burst

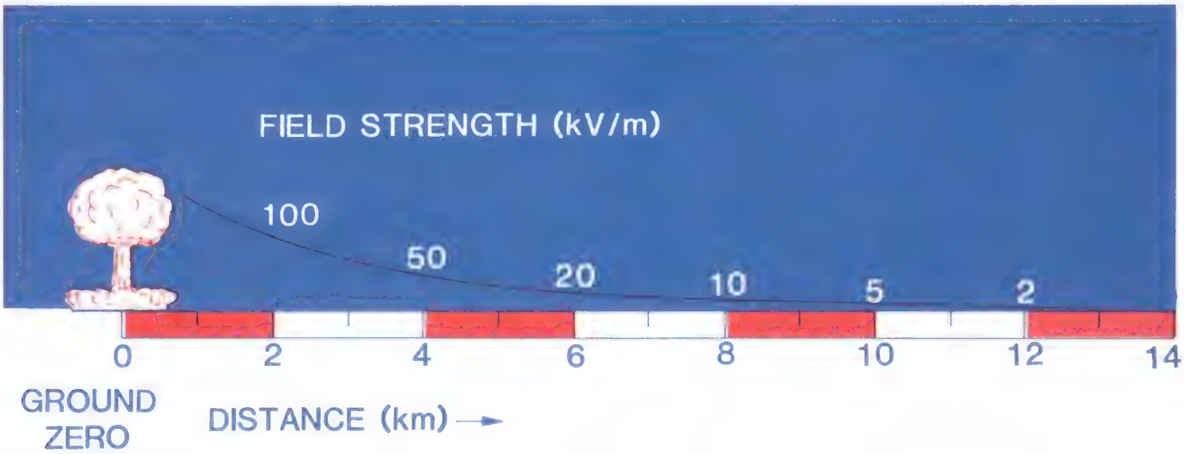


FIG. 530

Timescale of nuclear burst effects

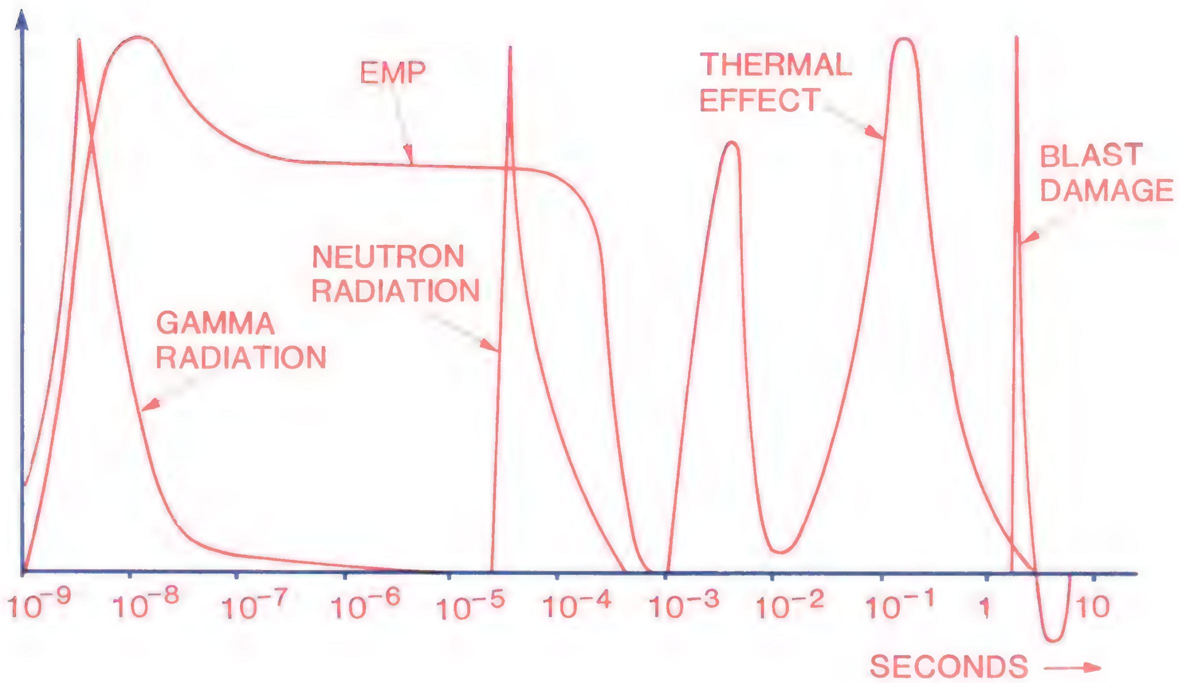


FIG. 510

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MINISTRY OF AVIATION

D1/57

DAMAGE BY NUCLEAR WEAPONS

A MANUAL OF BASIC TARGET RESPONSE DATA

SECURITY NOTE

This document has been issued in parts over an extended period and much of the earlier material now has a lower classification than it carried at the time of issue. Notwithstanding the grading shown on individual sheets dated earlier than March, 1959, the whole of the contents are now covered by the grading CONFIDENTIAL DISCREET.

Prepared by the Director General of Atomic Weapons
Ministry of Aviation.

CONFIDENTIAL DISCREET

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Prepared by the Director General of Atomic Weapons
Ministry of Aviation.

CONFIDENTIAL DISCREET

D1/57 Aug.1957

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Copy No .....

DAMAGE BY NUCLEAR WEAPONS

Amendment Certificate.

Amendment List Number	Date	Amendments Made By	Date
1			
2	7-9-60	M L Moore	7-9-60
3			
4			
5			
6			
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9			
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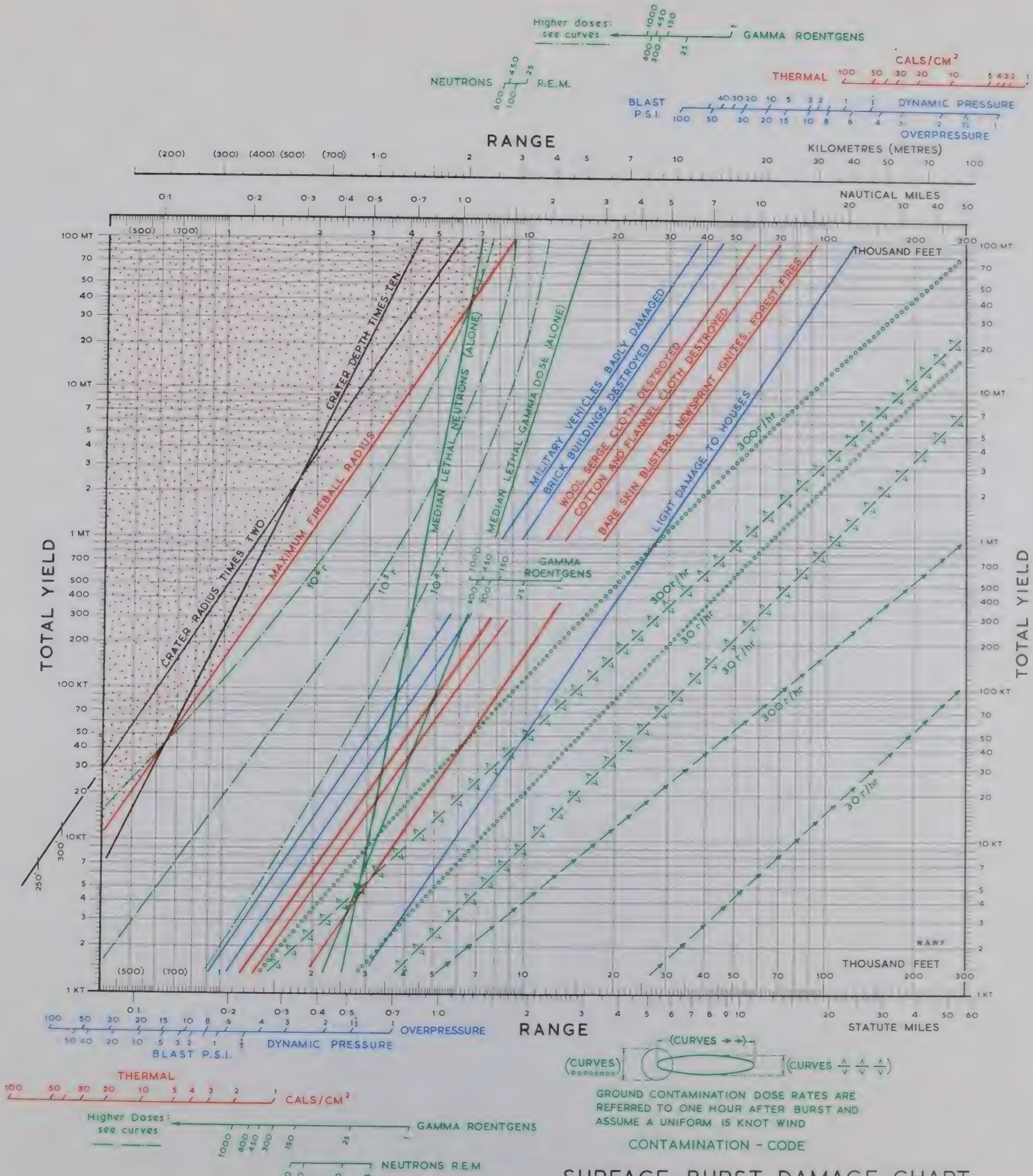
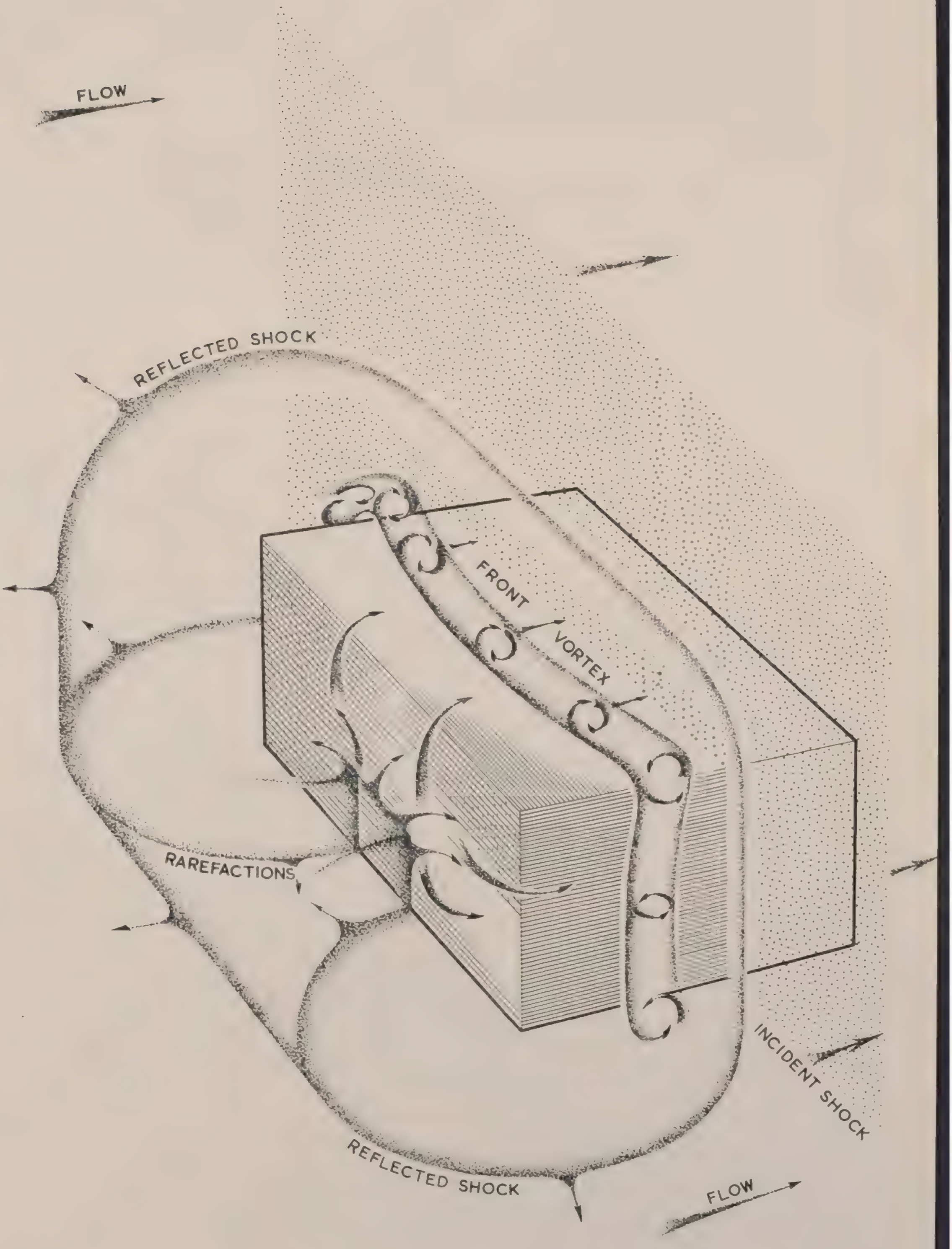


SURFACE BURST DAMAGE CHART



INTERACTION OF A SHOCK FRONT WITH THE FRONT OF A RECTANGULAR BUILDING

2.2.2. Rear wall

Figure 1 shows the main features of the time sequence of the static overpressure loading at a point on the rear wall of a rectangular structure. The time origin is taken as the instant at which the incident shock front reaches the rear edge of the building. The first diffracted shock reaches the point under consideration at A on the graph, followed by others until a sharp dip in the loading curve at B marks the onset of the rear vortex (see Section 2.1 Figure 2.) As the vortex moves away from the building the pressure rises and the flow phase CD follows. In general the pressure in this phase is rather higher than in the incident blast wave. The influence of the vortex is greatest at the edges of the wall and becomes negligible at about $\frac{1}{3}$ of the distance from the edge to the centre of the wall.

The above description is based on the results of experiments at the Atomic Weapons Research Establishment (1, 2) in which small-scale model buildings were exposed to the blast from a high explosive charge. An empirical analysis similar to that presented for the front wall in Section 2.2.1 has been undertaken. It has been found that for values of incident shock overpressure P_s in the range 3 to 20 p.s.i. the initial value of the shock diffracted through 90^o is $0.37\ P_s$. The diffracted shocks decay as they expand into the space behind the building according to the equation

$$p = 0.37\ P_s \left\{1 + \frac{0.103\ d}{W^{\frac{1}{3}}}\right\}^{-\frac{1}{2}} \qquad (2.8)$$

where d is the distance in feet travelled by the diffracted shock from the edge of the wall and W is the total yield of the explosion in kilotons.

This function is shown graphically in Figure 2. For values of P_s up to about 20 p.s.i. the interaction of diffracted shocks may be treated as additive. The correction which may have to be applied in the case of stronger shocks follows from normal theory.

The time of arrival of the individual shocks at a point is best estimated by taking the final strength of the shock from Figure 2 and assuming that it has travelled through undisturbed air at atmospheric pressure. The various errors introduced by these assumptions approximately cancel out.

Empirical relationships to represent the vortex effects have recently been worked out Reference (3), but at interior points of the wall the pressure behind the diffracted shocks follows the Friedlander form given in equation (1.2). At any point of the wall there will be four diffracted shocks, the one from the roof and its reflection from the ground, and one from each side. The equation of the loading curve is therefore

$$p = \sum_{i=1}^{4} p_i \left\{1 - \alpha(t - t_i)\right\} e^{-\alpha(t - t_i)} \qquad (2.9)$$

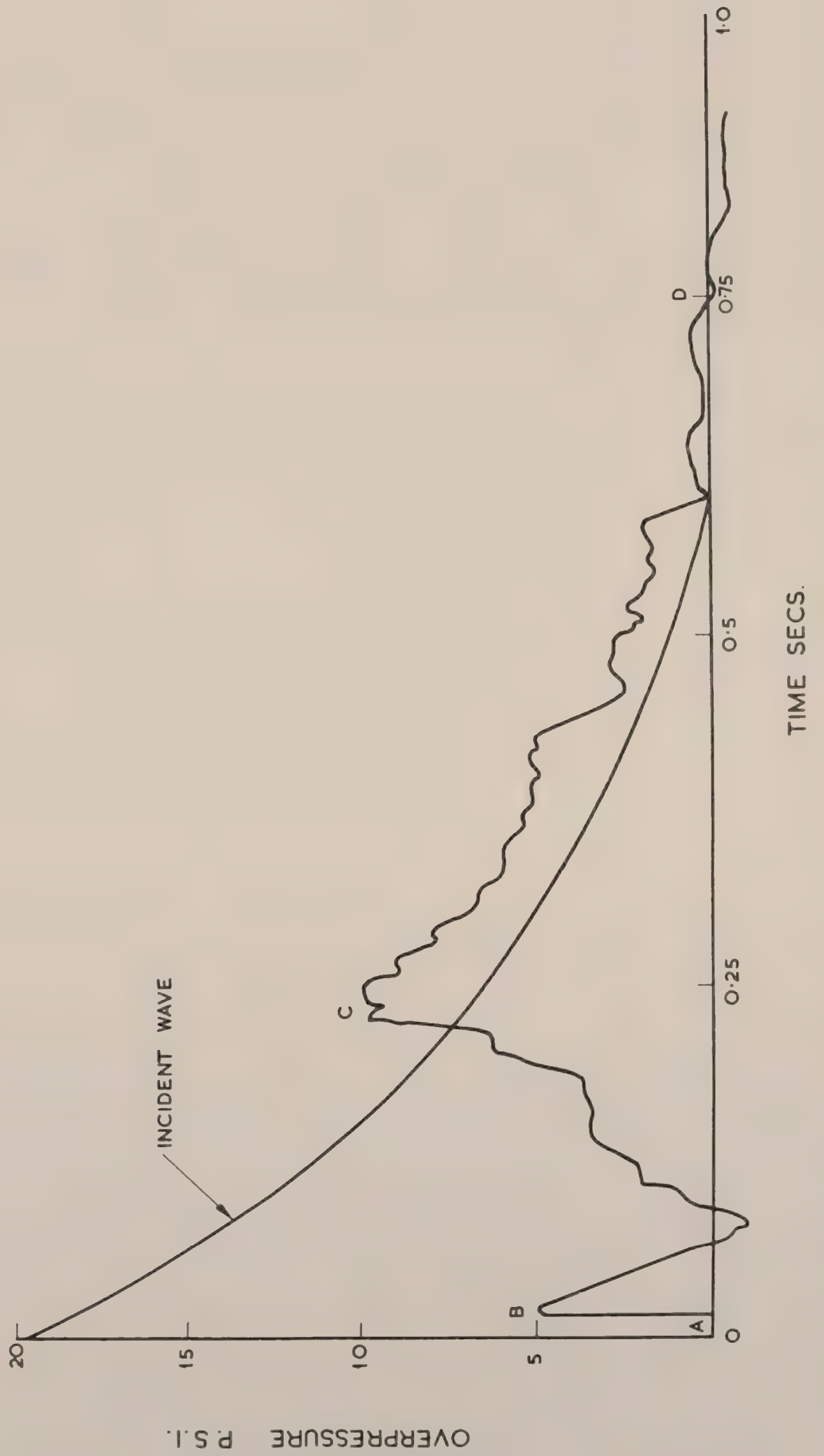
Each term of the summation starts at time t_i, and α is the reciprocal of the duration of the positive phase of the incident blast wave.

References

(1) Atomic Weapons Research Establishment Report No. E2/55
April 1955. (Confidential)
Model Experiments on the Loading of the Individual Plane Wall Panels of a Four Storey Block of Flats due to Atomic Blast. Rowe, R.D. et alia.

(2) A.W.R.E. Foulness Laboratory Note No. 3/53 (Confidential)

(3) A.W.R.E. Report No. E -/57. Loading of buildings by a large scale blast wave. II. Rowe, Samuels and Walford. (Confidential)



LOADING ON THE REAR WALL OF A BUILDING

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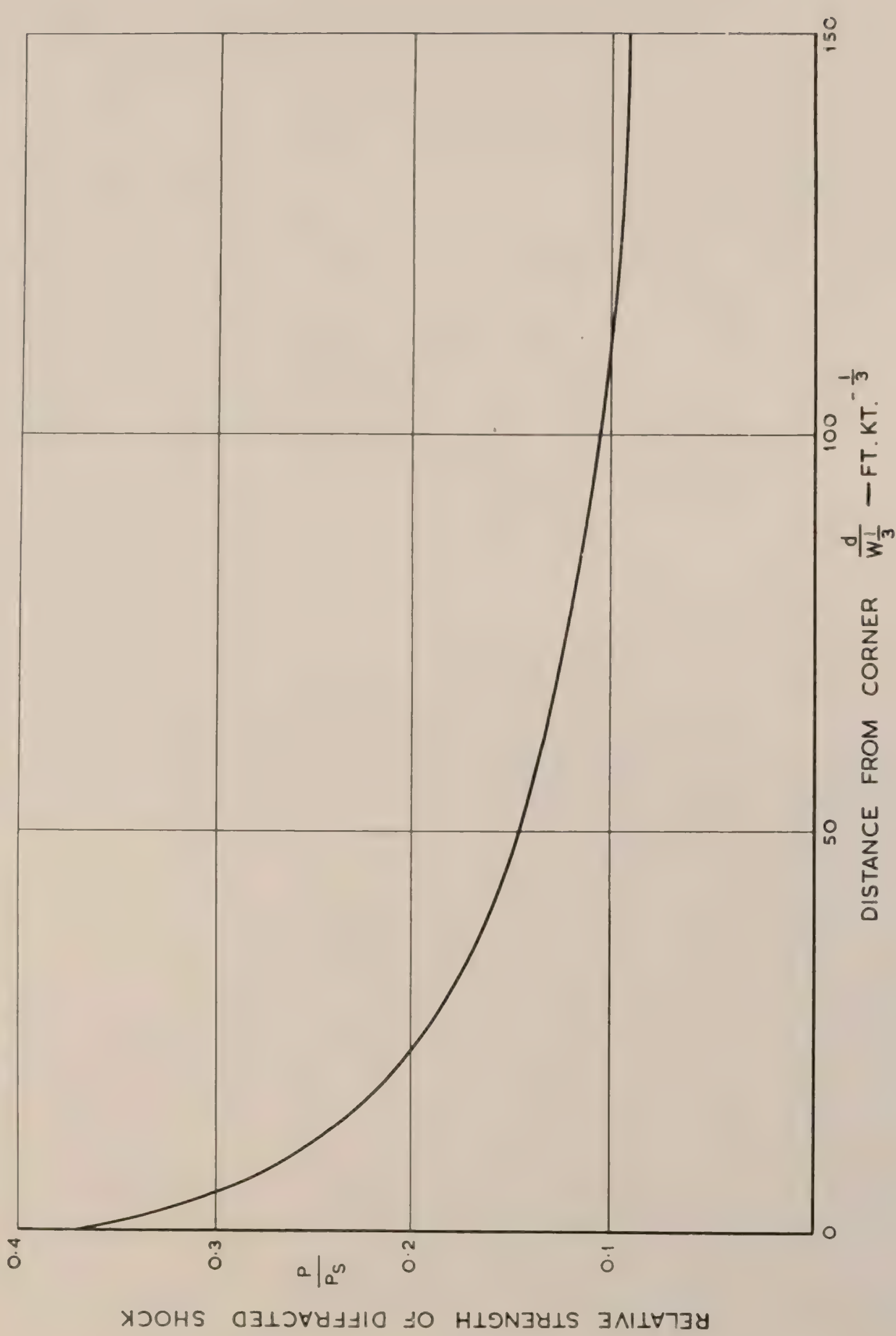
D.N.W.
AUG.1957



ATTENUATION OF A DIFFRACTED SHOCK

2.3 Translational and Overturning Forces

In order to obtain the resultant static force acting on a structure as a whole, it is necessary to determine the total force acting on the front and rear surfaces as a function of time, and to subtract one from the other, taking into account the time taken by the blast wave to travel the length of the structure. In some cases drag forces must also be considered. (see Section 2.4).

The force on the front surface can be found by dividing the surface into a grid of squares, and calculating the loading curve for the centre of each square by the method given in Section 2.2.1. As the only quantity in the loading formulae which varies with the position on the surface is the distance from the nearest edge, D_1 only a few calculations are required. For a square surface, a grid of 25 squares would normally be sufficient, giving three values of D_1. The loading at the centre of each square is assumed to represent the average pressure on the square.

As the point loading on the rear surface cannot be calculated accurately at present, the average pressure on the rear surface may be assumed to build up linearly to the incident blast pressure in the time $\frac{nS}{U}$, the empirical coefficient n is read from Figure 1. This figure is taken from reference (1) and is based on two-dimensional shock tube results and three-dimensional data from U.S. atomic weapon trials. U is the velocity of the incident shock wave as given in Figure 2, and S is the smaller of the height and the half-width of the surface.

Owing to the decay of pressure in the blast wave and the time lag between the loading of the front and rear surfaces, the resultant force on a structure in the flow phase will be directed towards the explosion if the structure is large enough. As an approximate rule this will occur if (L + 2S) is greater than $60W^{\frac{1}{3}}$, where L is the length of the structure in feet, S is the smaller of the height and half-width (also in feet) and W is the total yield of the weapon in kilotons.

Free-standing targets will be displaced or overturned by the blast. Such objects are usually small enough for all the blast forces to have passed before the object has moved appreciably. Thus the initial orientation may be taken for purposes of calculation; and moreover the loading will be such that drag will play an important part.

Sliding will occur, and for sufficient impulses, tipping or tumbling. The distinction, in the notation of Figure 3 is given by

$$\frac{T^2}{2I_A} \leqslant mgd\,(1-\sin\theta_o) \qquad (2.10)$$

for sliding, and for overturning

$$\frac{T^2}{2I_A} \geqslant 2\,mgd\,(1-\sin\theta_o) \qquad (2.11)$$

intermediate cases being in doubt.

In these equations T is the impulse, and I_A the moment of inertia of the target about the axis through A.

Evaluation of equations (2.10) and (2.11) is made in the following manner.

$$T = Ah \left[I_H + I_D - \frac{I_D}{10} \right] \qquad (2.12)$$

where h is the height of the centre of pressure, A is the side-on presented area of the target (assumed to be constant), I_H is the net translational static impulse, and I_D equals the drag impulse.

$$I_H = \frac{3}{2} \left[\frac{f}{C_r} (p_r - p_s) + \frac{b}{C_o} p_s \right] \qquad (2.13)$$

where f and b are the minimum distances from an edge to the centre of the front and rear faces respectively of the target in the side-on position, and C_r is the velocity of sound in the initial reflected pressure region and C_o the velocity of sound in undisturbed air (1130 ft/sec.).

Also, $$I_D = \frac{1}{5} p_d t_p \qquad (2.14)$$

where t_p is the positive duration of the pressure wave.

Further, $$I_A = m \left[\frac{W^2 + \chi^2}{12} + d^2 \right] \qquad (2.15)$$

where W is the width of the target and χ is "effective" height for the purpose of calculating I_A.

The target will therefore not overturn if

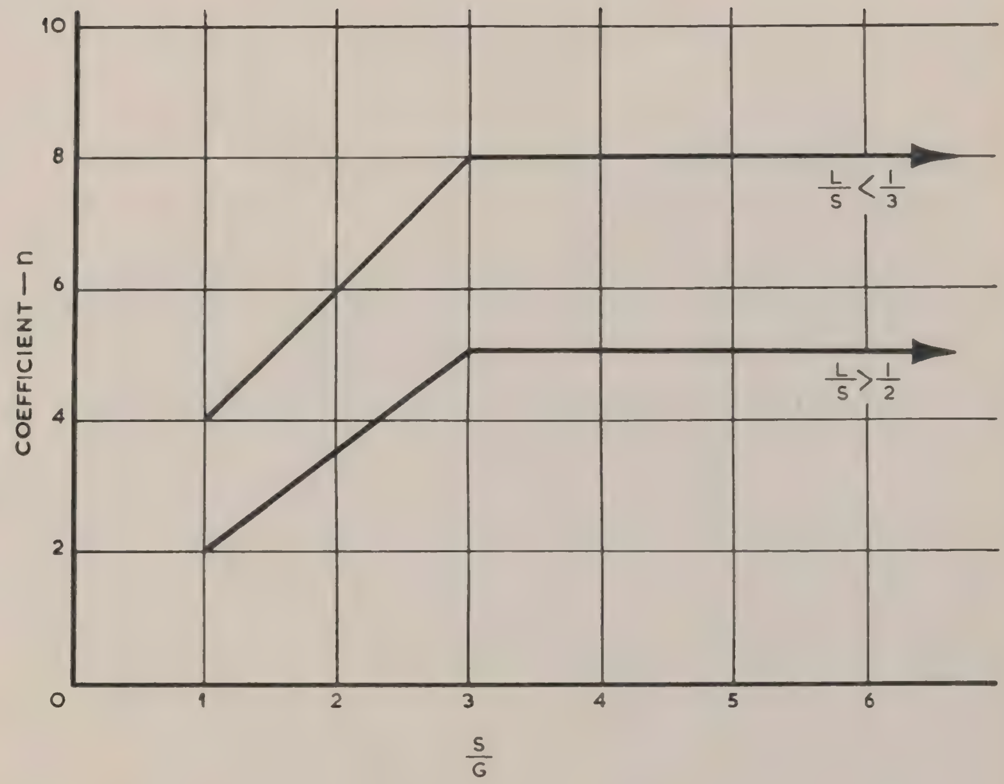
$$(I_H + 0.9 I_D) < \left[\frac{2I_A \, mgd \, (1 - \sin\theta_o)}{Ah} \right]^{\frac{1}{2}} \qquad (2.16)$$

Some applications to the megaton case are given in Reference (2)

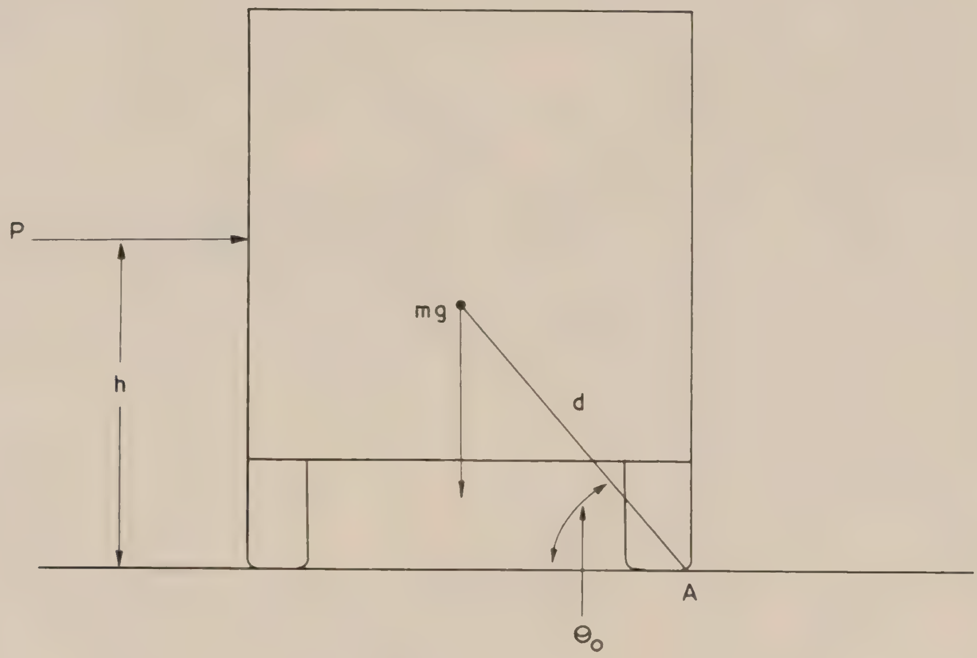
References

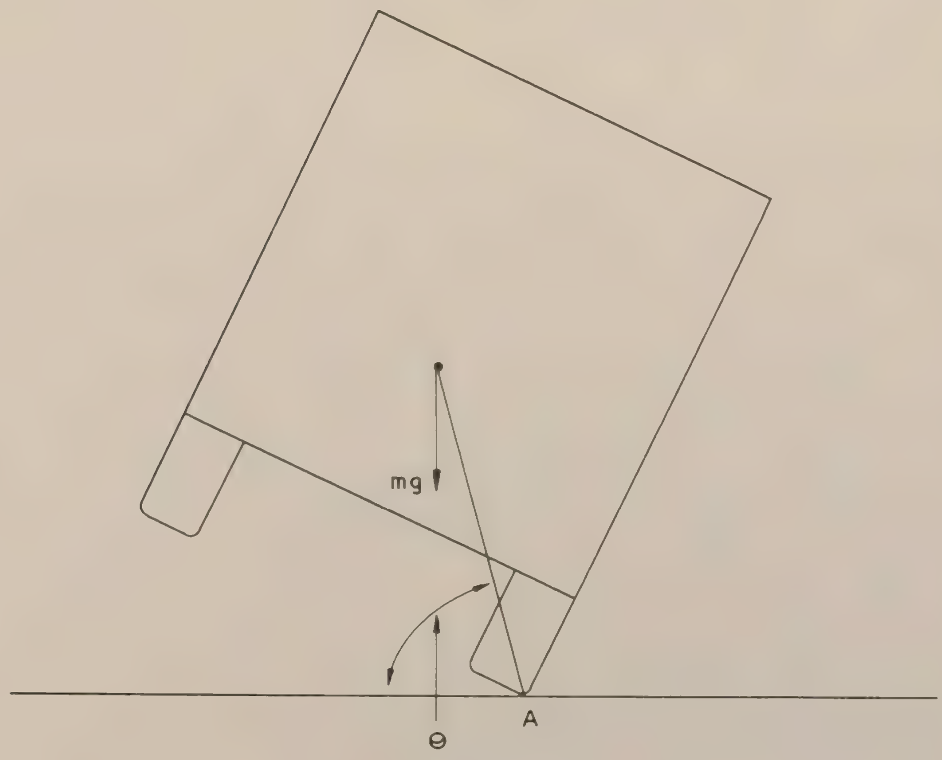
(1) Armour Research Foundation Project No. M024-1
Final Report (Report No.18) 1954 (Confidential/Discreet)

(2) Estimates of some blast wind effects of megaton bombs.
A.W.R.E. Report No.E6/55.
(Secret/Atomic/Discreet (Cleared for Canada))



BUILD-UP OF PRESSURE ON REAR WALL





OVERTURNING A FREE-STANDING TARGET

2.4. Drag Structures

Structures whose size is small compared with the region covered by the positive phase of the blast wave at a given moment are soon enveloped in the pressure wave so that its effects tend to be reduced in comparison with those due to the drag of the blast wind. This particularly applies to long thin structures such as chimney stacks or open steel frameworks, or to many types of vehicles and field equipment. Moreover it will be seen that the relative importance of drag forces increases with the yield of the weapon, affecting most targets in the case of megaton weapons.

This drag force on any given portion of the target is the product of the local dynamic pressure p_d, the presented area, and the drag coefficient for the section, C_d. Values of C_d have been determined for a number of shapes of section for study flows in wind tunnel experiments (1, 2, 3). These values are shown in Figure 1. Forces on complete structures may be approximated by summation of the forces on the separate parts. Detailed information is not available on drag coefficients for transient, variable speed flows.

In the absence of more relevant data, it is believed that the values given in Figure 1 may be used in blast loading calculations without serious error. The value of C_d for cylindrical sections depends on the Reynolds Number of the air flow which is defined as

$$Re = \frac{UL}{\nu} \quad ,$$

where U is the wind velocity, ν the kinematic viscosity (0.0001423 ft^2/sec^2 for air at N.T.P.), and L is a characteristic length such as height or diameter. Figure 1 gives the values of $\frac{Re}{L} = \frac{U}{\nu}$ immediately behind the shock front as a function of shock pressure p_s. The values were calculated for air pressure at 14.7 p.s.i. and temperature 17°C (62°F) ahead of the shock front.

The initial dynamic pressure is given by equation (1.1) and the variation with time in the blast wave by equation (1.4).

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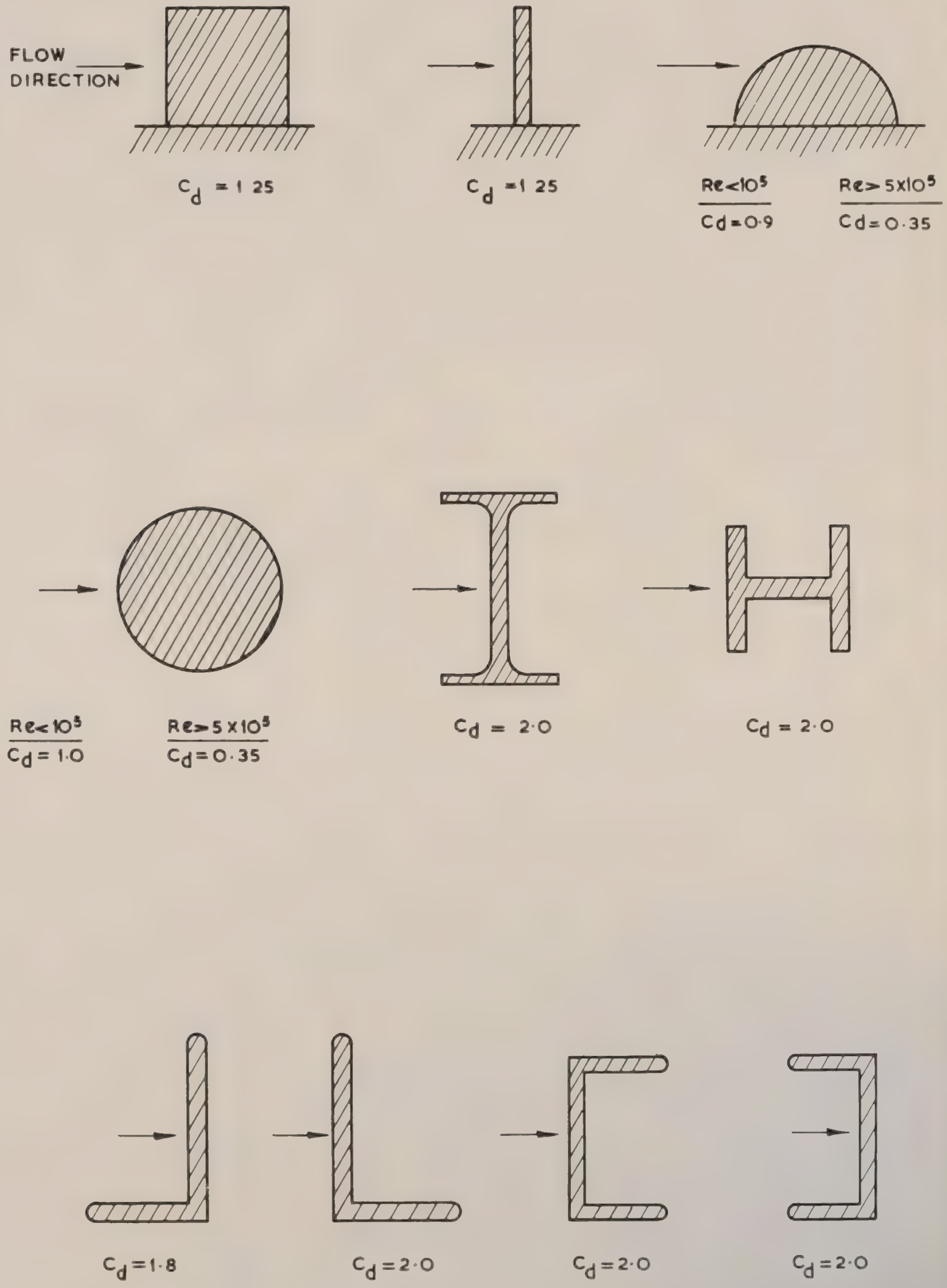
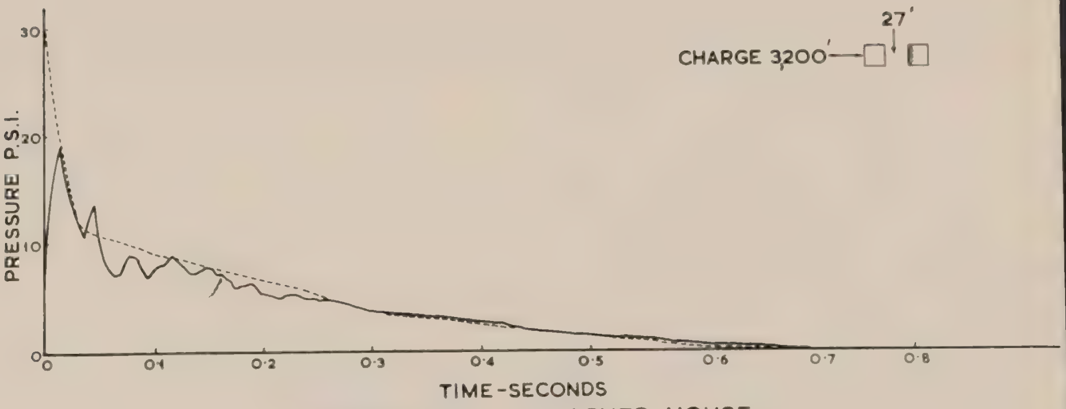
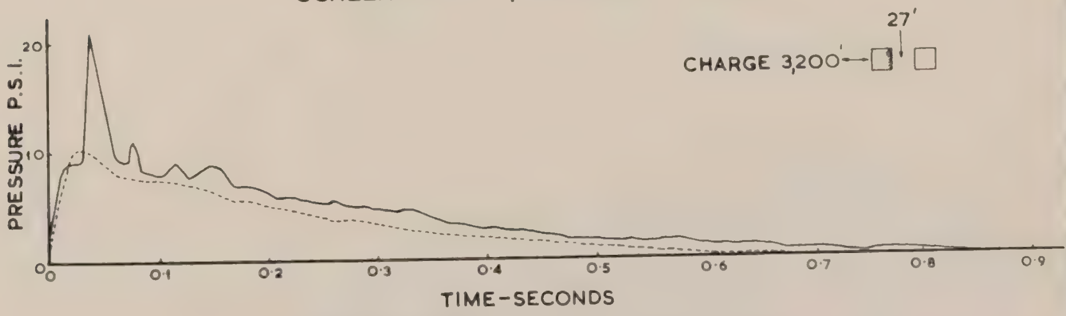


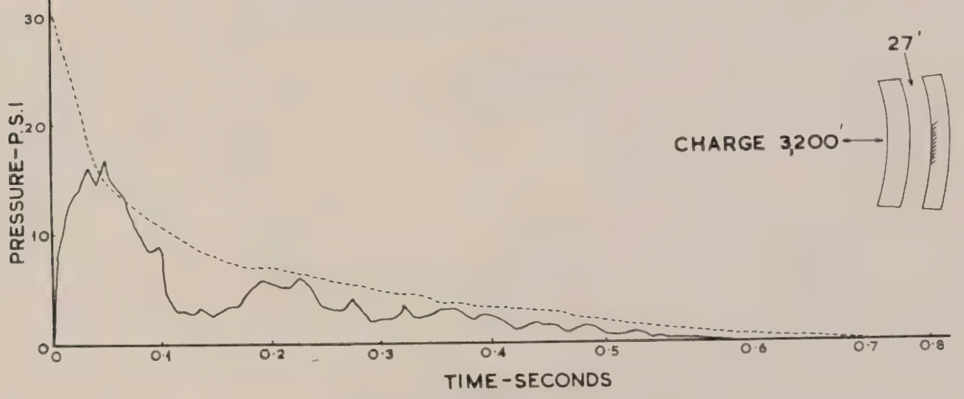
DRAG COEFFICIENTS



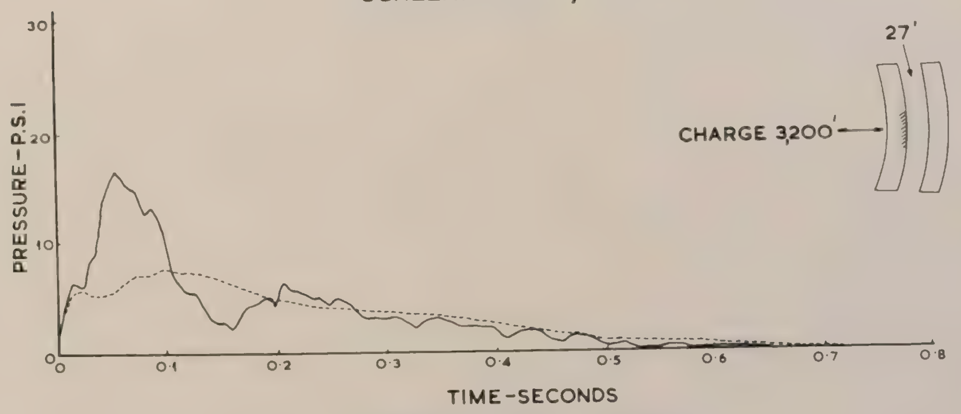
SCREENED WALL, DETACHED HOUSE



SCREENING WALL, DETACHED HOUSE



SCREENED WALL, TERRACE



SCREENING WALL TERRACE

THE EFFECT OF SHIELDING ON BLAST LOADING

SEPARATION EQUAL TO HEIGHT OF BUILDING

3.3. Earthworks to protect drag-sensitive targets

Targets, such as most military field equipment, which are relatively insensitive to overpressure, may be considerably protected from the dynamic effects of blast by earthworks. Effective shielding design must prevent the drag forces from impinging directly upon any part of the target item. Of possible shields, only earth mounds and trenches have proved themselves sufficiently immune against the effects of the blast. Optimum designs are still under study, but it is expected that if the drag loads can be largely eliminated, the vulnerability of the equipment will be reduced to its vulnerability to the crushing effect alone. In the Mach region of blast reflection this will probably produce only light damage at ranges where damage would otherwise have been severe. The severe isodamage curve would thus become a Light Damage contour for damage assessment purposes.

British experience of the protection given to stores by pits and mounds at Operation Totem is summarised in Section 4.16 of Reference (2).

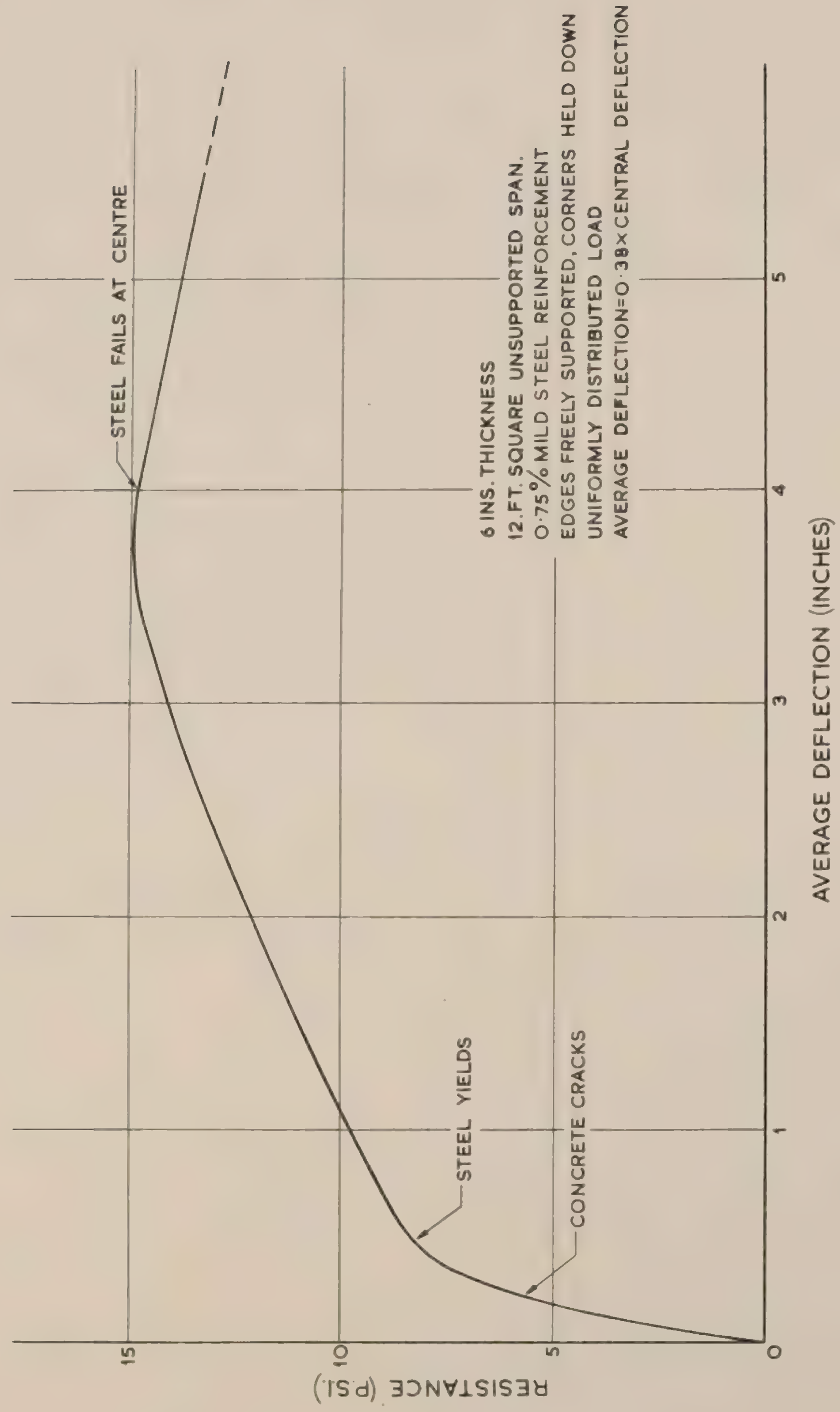
A small mound between Ground Zero and a side-on fighter aircraft gave negligible protection, (Reference (3)).

References

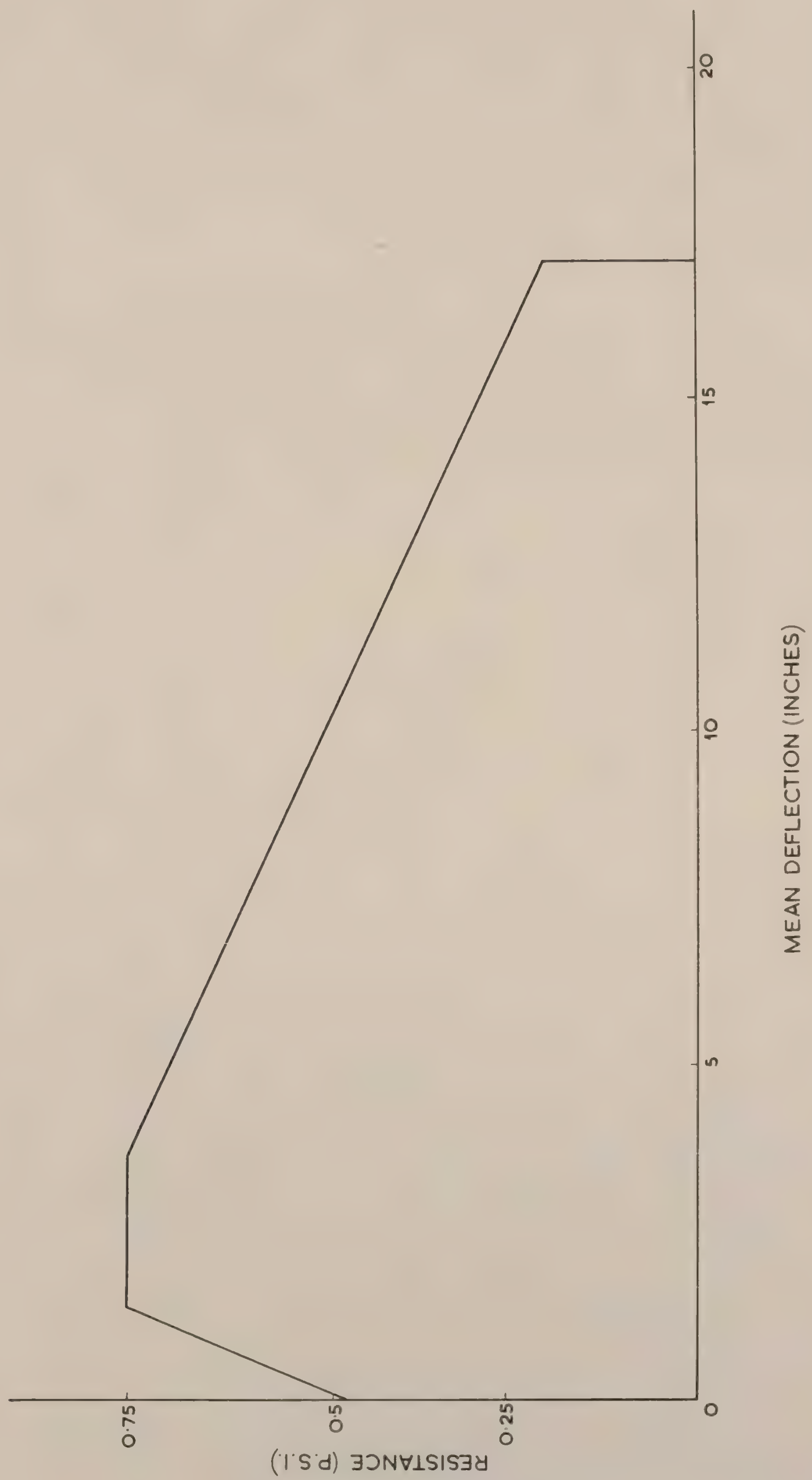
(1) Reduction of Blast Damage by Shielding
Presentation by Major Richard J. Hesse at Conference on the Effects of Blast on Military Field Equipment, A.F.S. W.P. 29th February, 1956. (Secret/Atomic)

(2) The effects of an atomic explosion upon Ammunition. Operation Totem. Major L. Cave, R.A.O.C. A.W.R.E. Report T84/54 (Secret)

(3) The effects of Totem 1 explosion on aircraft of stressed skin construction. Offord and Noble A.W.R.E. Report T112/54 (Confidential)



STATIC LOAD/DEFLECTION CURVE FOR REINFORCED CONCRETE PANEL

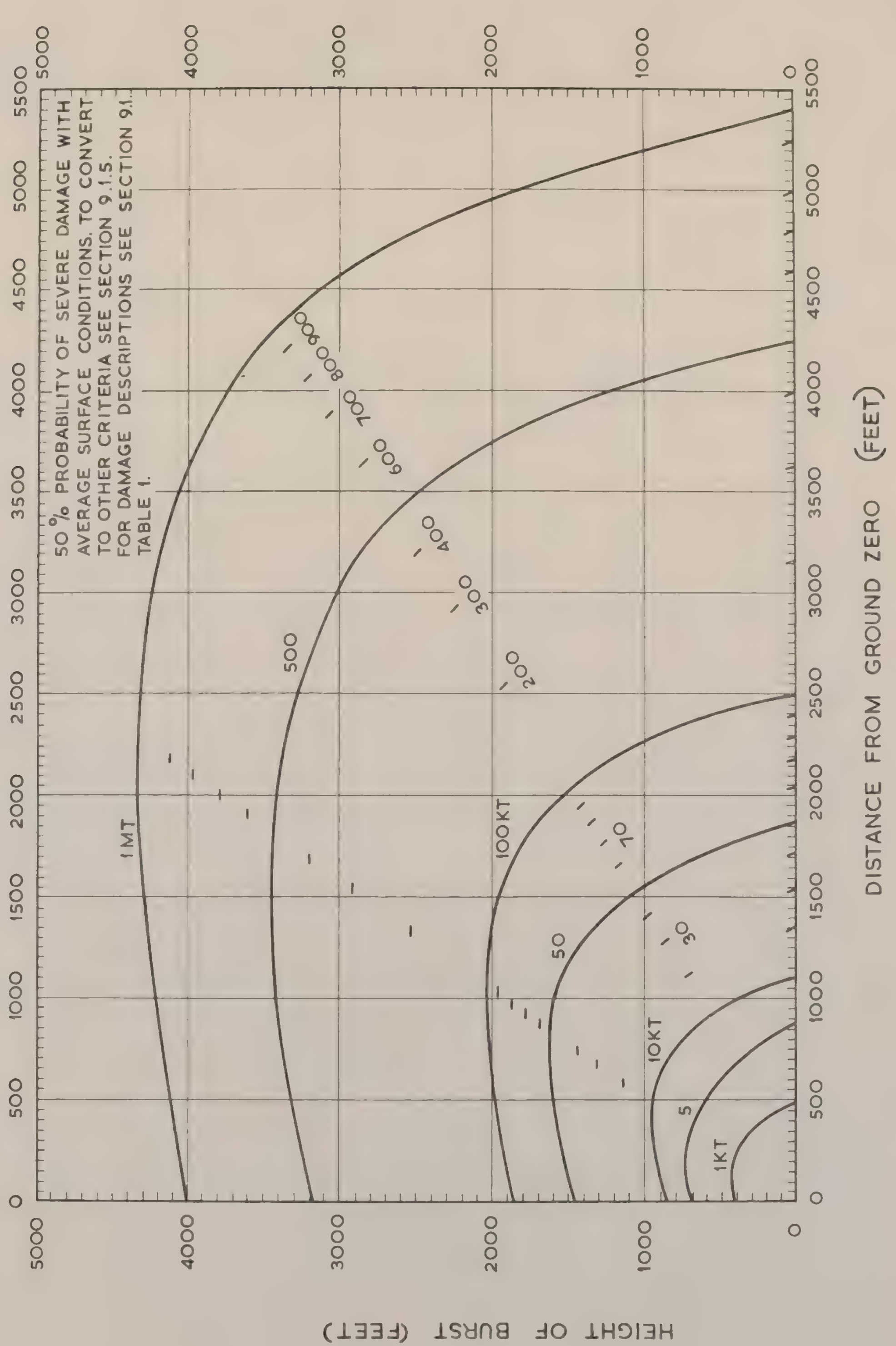


RESISTANCE / DEFLECTION CURVE FOR HOUSE WITH LOAD-BEARING WALLS

TABLE I - Damage to Structural Types Primarily Affected by Blast Wave Overpressure during the Diffraction Process

Section	Fig.No.	Description of Structure	Description of Damage		
			Severe	Moderate	Light
9.2.2.	1	Multistory reinforced concrete building with reinforced concrete walls, blast resistant designed, no windows, three storey.	Walls shattered, severe frame distortion, incipient collapse of first floor columns.	Walls cracked building slightly distorted, entranceways damaged, doors blown in or jammed. Some spalling of concrete.	
9.2.2.	2	Multistory reinforced concrete building with concrete walls, small window area, five storey.	Walls shattered, severe frame distortion, incipient collapse of first floor columns.	Exterior walls badly cracked. Interior partitions badly cracked or blown down. Structural frame permanently distorted; spalling of concrete.	Windows and doors blown in. Interior partitions cracked.
9.2.3.	1	Multistory reinforced concrete frame office type building five storey. Light weight low strength walls fail quickly.	Severe frame distortion. Incipient collapse of lower floor columns.	Frame distorted moderately. Interior partitions blown down. Some spalling of concrete.	Windows and doors blown in. Light siding ripped off. Interior partitions cracked.
9.2.4.	1	Multistory steel frame office type building, five storey. Light weight low strength walls fail quickly.	Severe frame distortion. Incipient collapse of lower floor columns.	Frame distorted moderately. Interior partitions blown down.	Windows and doors blown in. Light siding ripped off. Interior partitions cracked.
9.2.5.	1	Heavy steel frame industrial building, single storey, with 50 ton crane capacity. Light weight low strength walls fail quickly.	Severe distortion of frame (½ column height deflection).	Some distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in. Light siding ripped off.
9.2.5.	2	Medium steel frame industrial building, single storey, with 20 ton crane capacity. Light weight low strength walls fail quickly.	Severe distortion of frame (½ column height deflection).	Some distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in. Light siding ripped off.
9.2.5.	3	Light steel frame industrial building, single storey, with up to 5 ton crane capacity. Light weight low strength walls fail quickly.	Severe distortion of frame (½ column height deflection).	Some distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in. Light siding ripped off.
9.2.6.	1	Multistory wall bearing building, monumental type four storey.	Bearing walls collapse resulting in collapse of structure supported by these walls. Some bearing walls may be shielded enough by intervening walls so part of structure may receive only moderate damage.	Exterior walls facing blast badly cracked, interior partitions badly cracked, although toward far end of building damage may be reduced.	Windows and doors blown in. Interior partitions cracked.
9.2.6.	2	Multistory wall bearing building, brick apartment house type, up to three storey.	Bearing walls collapse resulting in total collapse of structure.	Exterior walls badly cracked, interior partitions badly cracked or blown down.	Windows and doors blown in. Interior partitions cracked.
9.2.7.	1	Wooden frame building, house type, one or two stories.	Frame shattered so that structure is for the most part collapsed.	Wall framing cracked. Roof badly damaged. Interior partitions blown down.	Windows and doors blown in. Interior partitions cracked.
9.2.8.	2	Highway and railroad truss bridges, spans of 150ft. to 250ft. (See figure title for effects of orientation.)	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50%	Capacity of bridge unchanged. Slight distortion of some bridge components (use Q - 0.6 psi curve scaled to weapon yield.
9.2.8.	3	Highway and railroad truss bridges, spans 250ft. to 550ft. (See figure title for effects of orientation.)	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50%.	Capacity of bridge unchanged. Slight distortion of some bridge components. (Use q = 0.6 psi curve scaled to weapon yield.)
9.2.8.	4	Floating bridges, U.S. Army Standard M-2 and M-4, random orientation.	All anchorages torn loose, connections between treadways or balk and floats twisted and torn loose, many floats sunk.	Many bridle lines broken, bridge shifted on abutments, some connections between treadways or balk and floats torn loose.	Some bridle lines broken, bridge capacity unimpaired.
9.2.9.	1	Oil tanks, 30ft. in height, 50ft. in diameter. (Tanks considered full; more vulnerable if empty.	Large distortions of sides, seams split, so that most of contents are lost.	Roof collapsed, sides above liquid buckled, some distortion below liquid level.	Roof badly damaged.

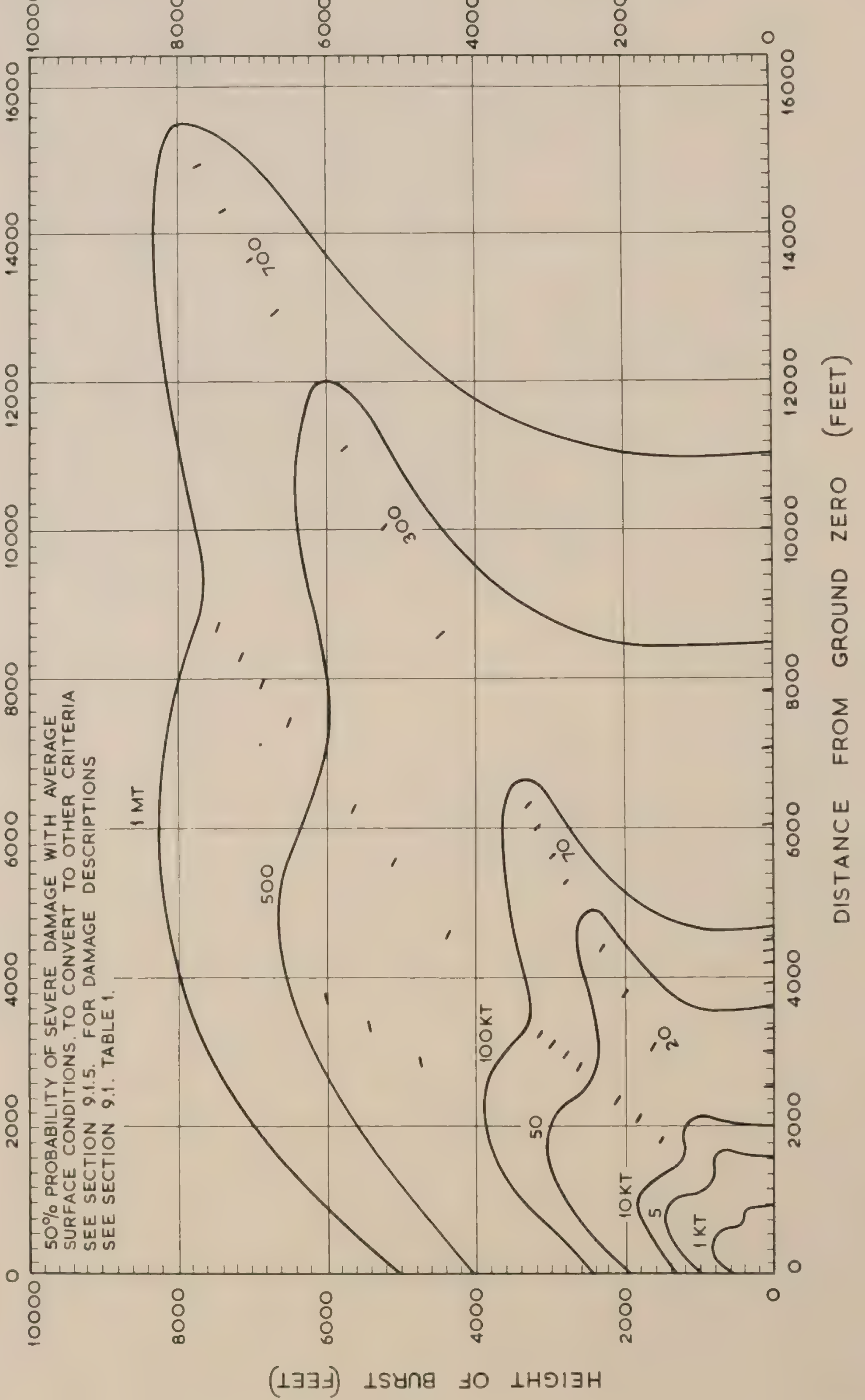
SECRET ATOMIC



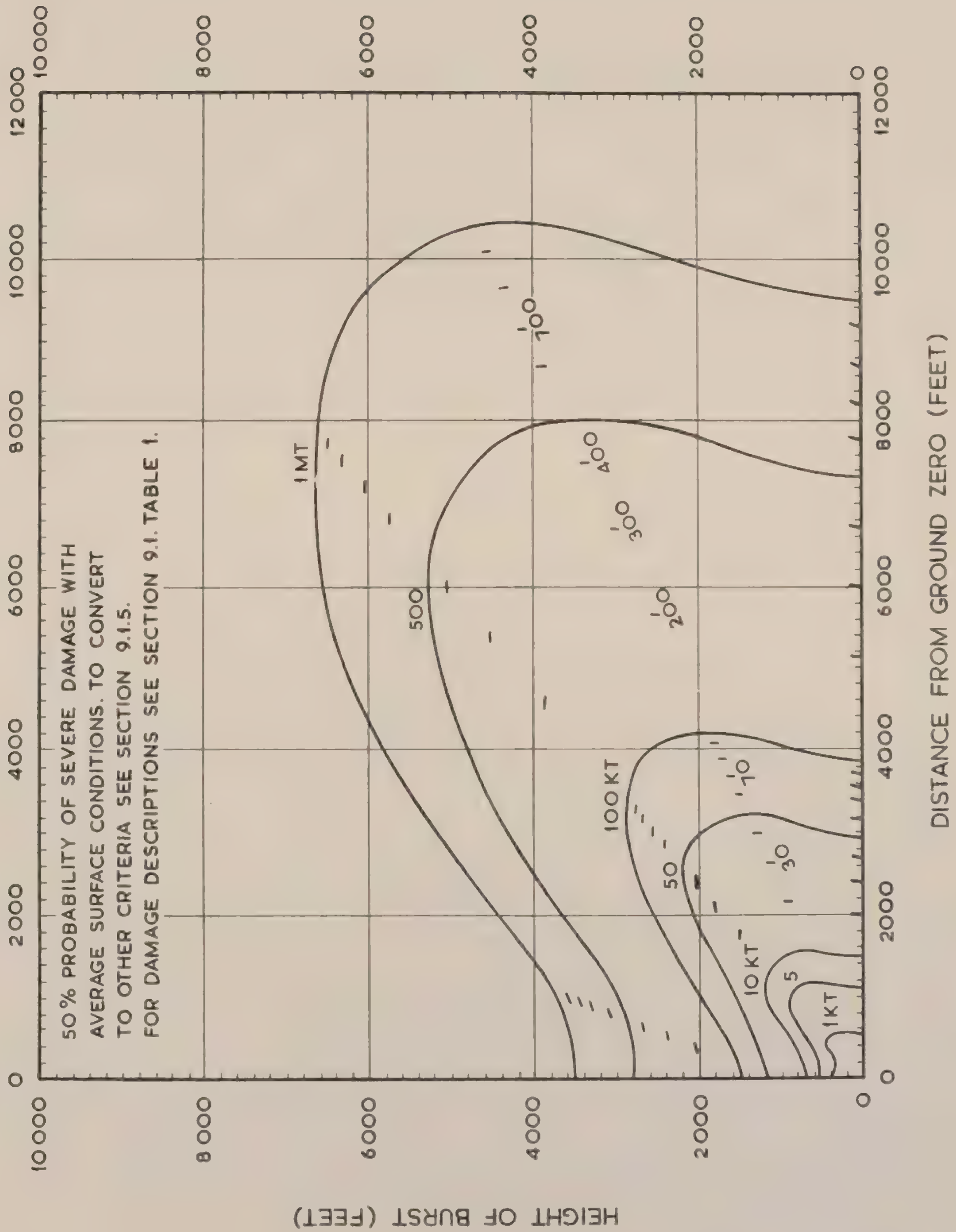
DAMAGE TO REINFORCED CONCRETE 3-STOREY CITADELS WITH REINFORCED CONCRETE WALLS.

SECRET ATOMIC

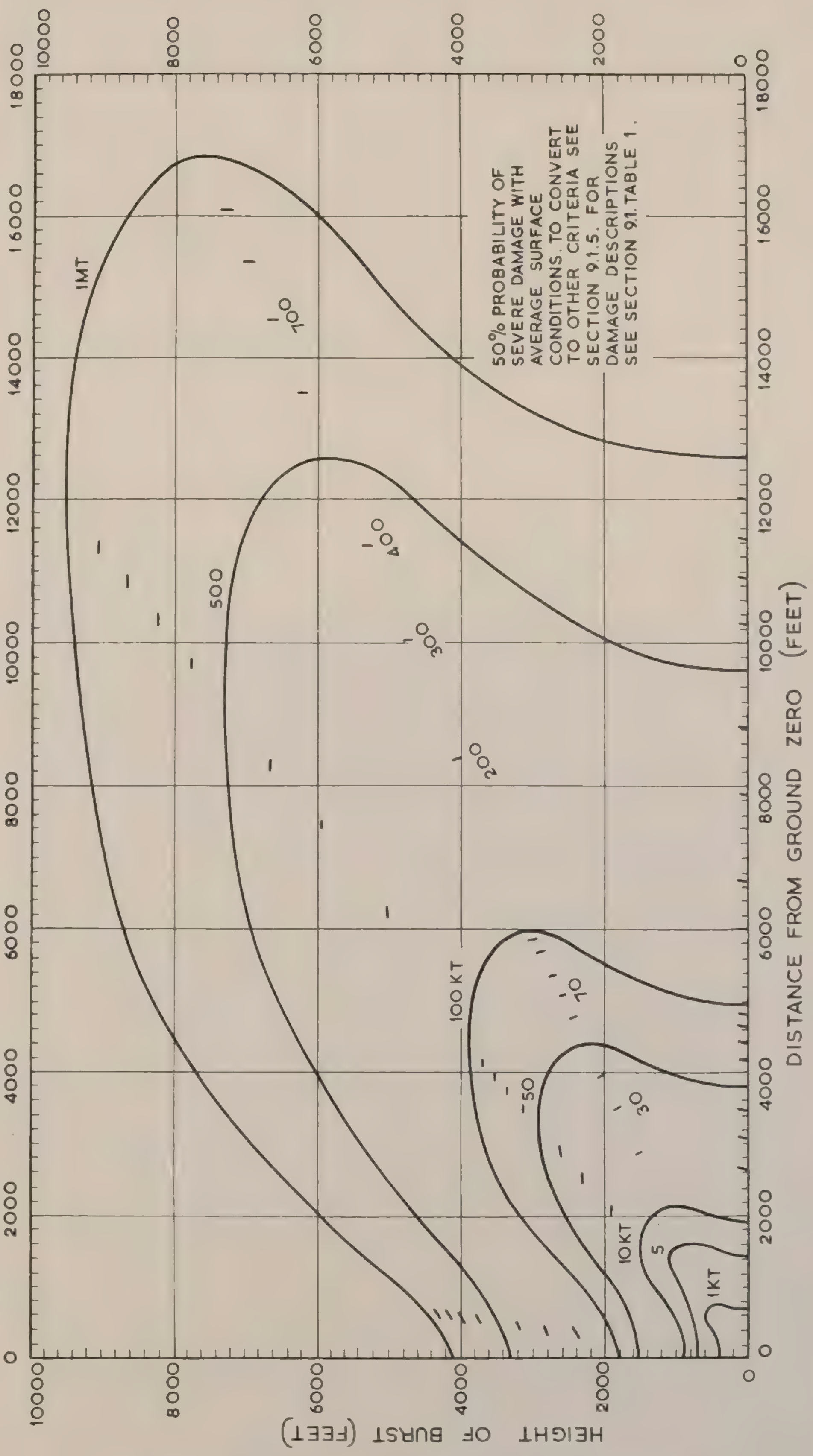
PART III
CHAPTER 9
SECTION 9.2.2.
FIGURE 2



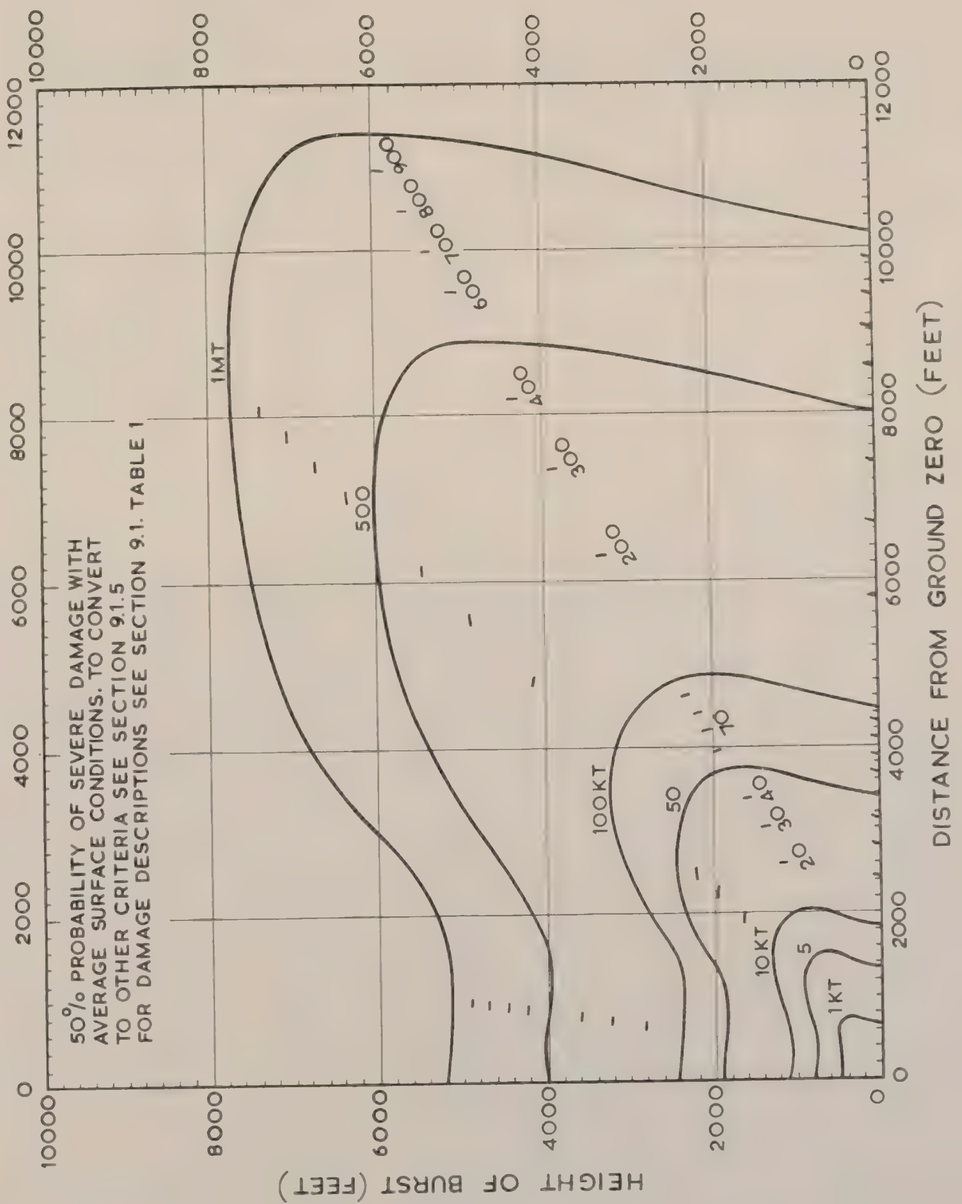
DAMAGE TO REINFORCED CONCRETE 5-STOREY
BUILDINGS WITH UNREINFORCED CONCRETE WALLS.



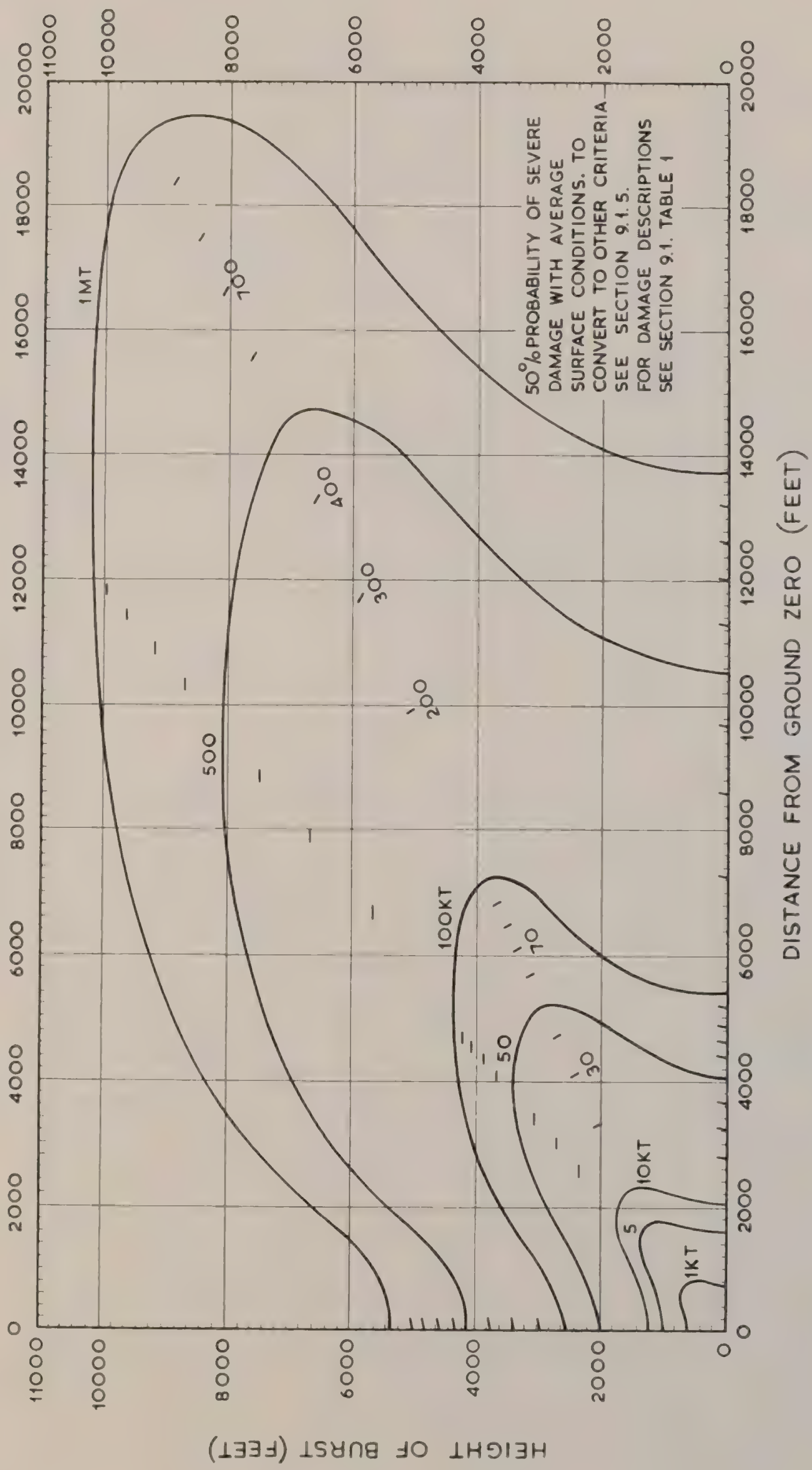
DAMAGE TO 5-STOREY REINFORCED CONCRETE FRAME OFFICE-TYPE BUILDINGS WITH LIGHT WALLS.



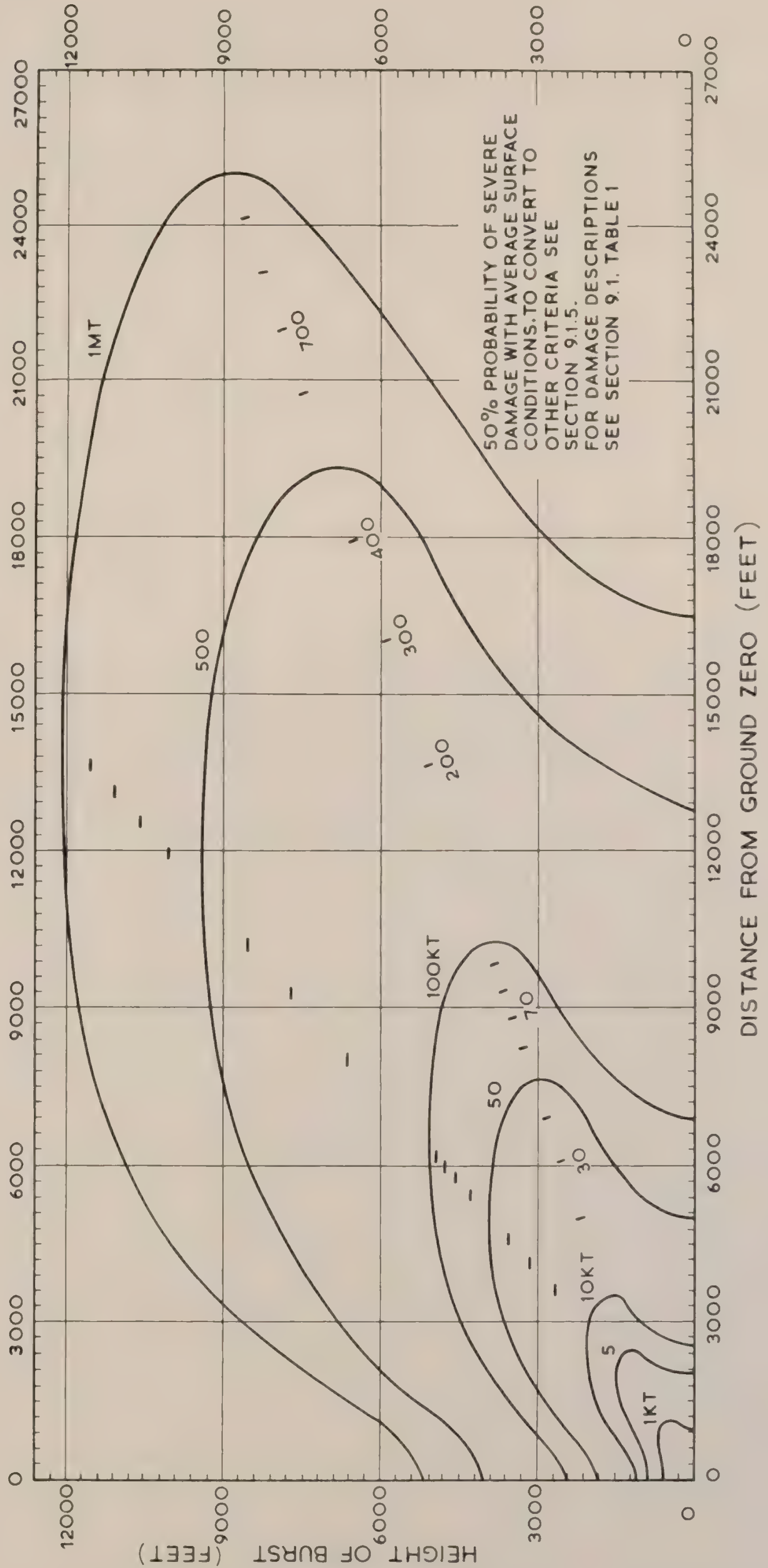
DAMAGE TO 5-STOREY STEEL FRAME
OFFICE-TYPE BUILDINGS WITH LIGHT WALLS



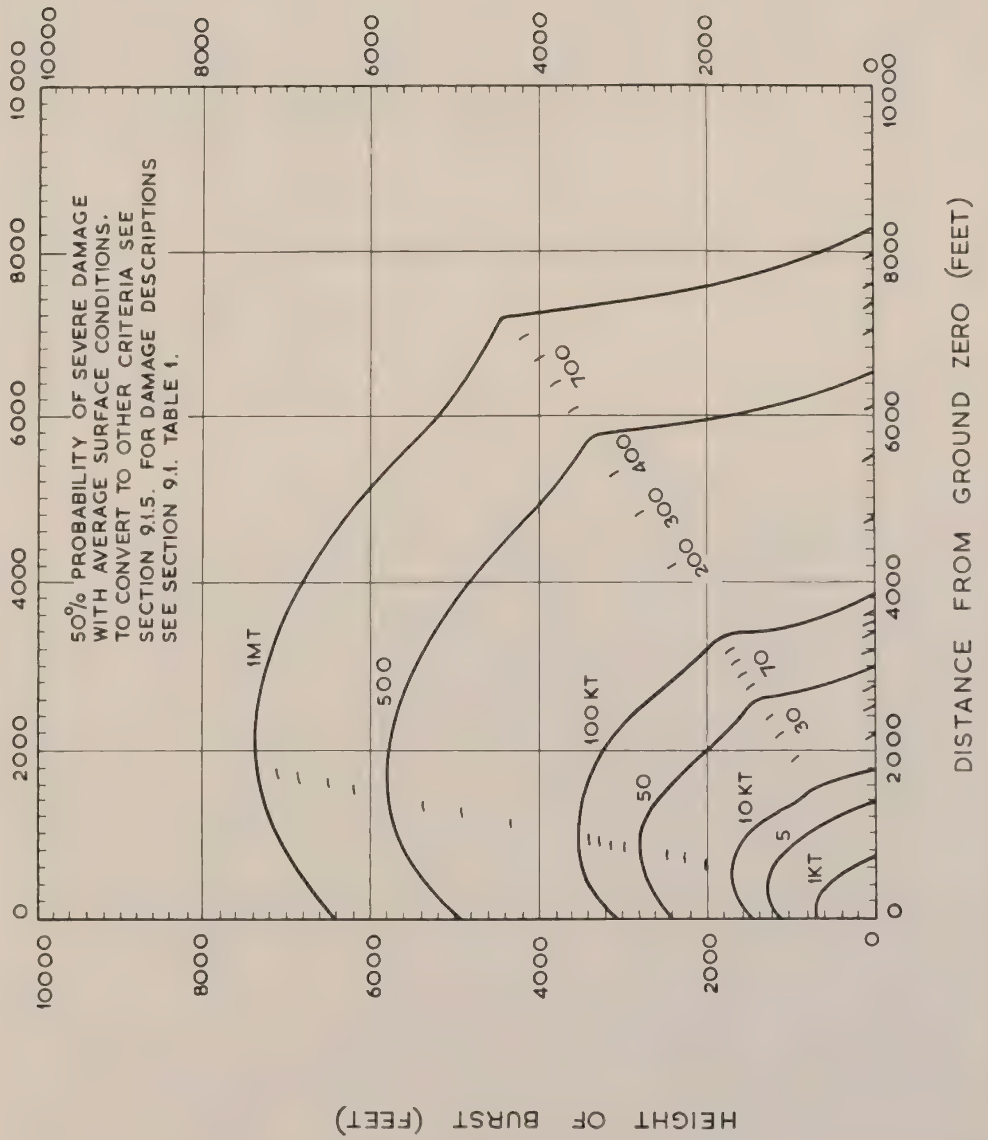
DAMAGE TO HEAVY STEEL FRAME INDUSTRIAL BUILDINGS WITH LIGHT WALLS



DAMAGE TO MEDIUM STEEL FRAME INDUSTRIAL BUILDINGS WITH LIGHT WALLS



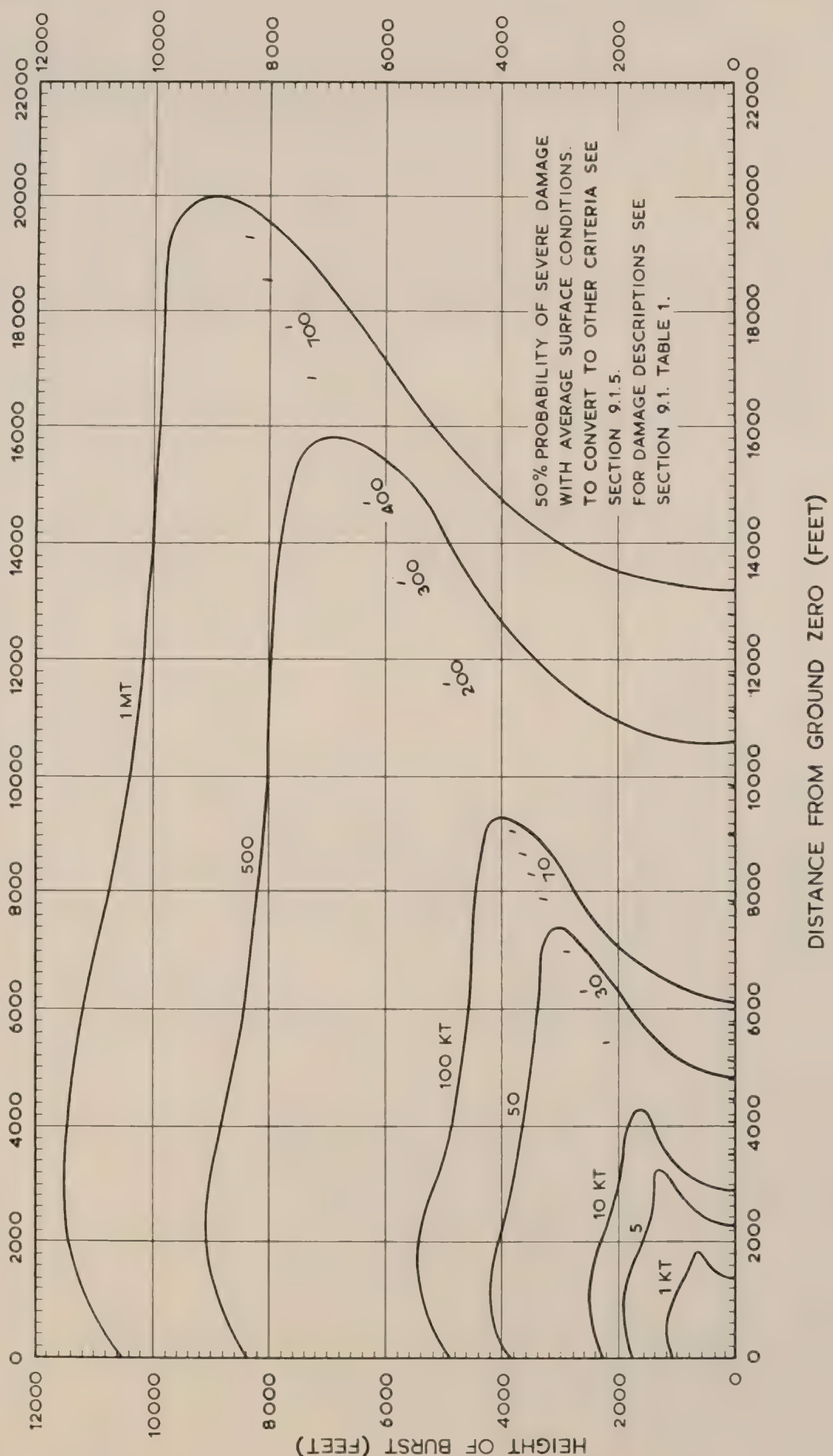
DAMAGE TO LIGHT STEEL FRAME INDUSTRIAL BUILDINGS WITH LIGHT WALLS



DAMAGE TO MONUMENTAL TYPE 4-STOREY BUILDINGS WITH LOAD-BEARING WALLS

D.N.W.
SEPT. 1957

SECRET ATOMIC



DAMAGE TO U.S. APARTMENT-HOUSE TYPE
BUILDINGS UP TO 3 STOREYS

Z.15234.R.

SECRET ATOMIC

The dummies were dressed in worn service uniform: khaki shirt, battledress, socks and boots. This was specified because clothing obviously influences the drag coefficient of man exposed to the blast wave. It has been reported that clothing was torn away completely from survivors at Hiroshima and Nagasaki.

The effects of the forces acting on the dummies were followed by estimating the displacement of the dummies, and from accelerometer and cinematograph records where these were available. Since the effects would depend upon friction and upon the area exposed to the weapon, six postures were chosen. Standing, crouching and lying were selected as representing three stages in evasive action. Each of these positions was duplicated, facing (or head towards), and sideways-on to the weapon. Each of these six postures was exposed at five ranges, as shown in Table 1 below. The presented areas of the dummies are given in Table 2.

TABLE 1

Layout of Dummies Clad in Battledress

Site No.	Range from G.Z. ft.	Posture of Dummy					
		Prone		Crouching		Standing	
		Facing	Side-ways	Facing	Side-ways	Facing	Side-ways
1	1840	+	+				
2	2056	+	+				
3	2200	+	+	+	+		
4	2390	+	+	+	+	+	+
5	2656	+	+	+	+	+	+
6	3110			+	+	+	+
7	3900			+	+	+	+
8	6000					+	+

TABLE 2

Areas presented by the dummies towards the explosion

Posture	Area in square feet: Facing explosion	Sideways-on
Prone	1	5
Crouching	4	5
Standing	10	5

Results

The results in terms of displacements of the dummies, together with the estimated pressures which occurred at the various ranges are given in Table 3.

TABLE 3

Displacements Classified According to Drag Pressure
Posture and Orientation

Range from G.Z. ft.	Drag Pressure p.s.i.	Over-pressure p.s.i.	Posture					
			Prone		Crouching		Standing	
			F ft.	S ft.	F ft.	S ft.	F ft.	S ft.
1840	7.4	18†	42	66	-	-	-	-
2056	4.4	14.5	2.5	69	-	-	-	-
2200	3.7	12	2	20	15	39	-	-
2390	2.7	10	1	8*	16	18	35	20
2656	1.9	8.5	1	24	9	9	30	16
3110	1	6.4	-	-	6	9	16	10
3900	0.43	4.3	-	-	1	3(4)	4(7)	3(6)
6000	0.11	2.4	-	-	-	-	2(5)	0

*This dummy was sited on firm rocky ground. All others were sited on soft ground.

†Multiple peaks in overpressure record.

In certain cases in Table 3 additional information is given in parenthesis: these figures represent the actual displacements of the centres of gravity, which were corrected for displacement through the final toppling over from the standing or crouching position.

Electrical circuit failure prevented time resolution of accelerometer records and only peak accelerations in the vertical, lateral and longitudinal planes became available for analysis. The peak accelerations in the plane of initial displacements for the instrumented dummies are shown in Table 4.

TABLE 4.

Maximal Positive Accelerations Recorded in the Planes of Initial Displacement of the Dummy Men Exposed in the Open

Range feet	Posture and Plane					
	Prone		Crouching		Standing	
	Facing Vertical g	Sideways Lateral g	Facing Vertical g	Sideways Lateral g	Facing Longitudinal g	Sideways Lateral g
1840	14	14				
2200	9	12	7	19		
2390					26	24
2656	4	7	11	13		
3110					*	55
3900			6	7		
6000					13	3

*Burned out.

It was presumed that the maximum decelerations recorded occurred at the terminal collision with the ground. These results should give some indication of the damage sustained, and are quoted in Table 5.

TABLE 5

Maximal Decelerations Derived from Accelerometer Results Classified According to Range Posture and Orientation

Range Feet	Posture					
	Prone		Crouching		Standing	
	Facing g	Sideways g	Facing g	Sideways g	Facing g	Sideways g
1840	18	35				
2200	18	17	17	15		
2390					53	11
2656	12	17	26	11		
3110					*	22
3900			0	26		
6000					16	5

*Burned out.

Records were also made of joint changes and displacement of steel helmets.

It is noted from Table 3 that for any drag pressure, the displacement of the dummies oriented sideways-on is of the same order, irrespective of posture. This implies that friction with the ground did not impede take-off of the prone and crouching dummies.

From (i) the drag pressure, (ii) the surface area presented to the explosion, and (iii) the duration of the blast wind, it is possible to calculate impulse. This is proportional to the product of (i) x (ii) x (iii).

Using the figures for presented area given in Table 2 above, together with data for drag pressures and wind durations, a curve for the relationship between impulse and displacement has been constructed. Figure 1 shows this relationship. This solid line is the regression curve calculated to fit the results. It has the form:-

$$\text{displacement (feet)} = \left(\frac{A \times P \times T}{1660}\right)^{1.5}$$

where A = presented area (in^2)

P = peak drag pressure (p.s.i.),

T = duration of positive phase (sec.)

The dotted lines in Figure 1 show the 95% confidence limits based on the fore-going data.

Regarding the accelerometer data, there was firm correlation between initial acceleration recorded and the displacement suffered. The correlation between displacement and maximal decelerations is poor, and no

correlation can be recognized between deceleration and severity of damage to the dummy. It is apparent therefore that while some displacement must occur to cause injury, injury or damage depends more upon the detailed nature of the terminal collision than upon the magnitude of the displacement or rapidity of deceleration.

Conclusions

In attempting to deduce what would have been the fate of soldiers exposed in the same way as the dummies the authors of Reference (2) conclude that:-

(1) All such soldiers would have suffered severe flash burns on exposed skin.

(2) All such soldiers within 3500 ft. (i.e. Sites No.1-6) would have suffered serious, lethal, radiation illness.

(3) All soldiers beyond 4000 ft. in open country would have suffered little or no injury from blast displacement per se.

(4) Soldiers at ranges of less than 2250 ft. would probably have suffered moderate to very severe injuries from blast displacement per se. (Three metal limbs were disarticulated in this zone).

(5) The severity of injury would have been roughly proportional to the surface area presented to the blast wave. Thus crouching and standing dummies show greater displacement than prone dummies at similar ranges. Similarly prone dummies exposed sideways-on to the explosion suffered greater displacement than prone dummies with heads towards Ground Zero.

In view of the observed displacement of steel helmets it is further concluded that wearing the retaining strap of a steel helmet under the chin is inadvisable, and that steel helmets might possibly become dangerous missiles, especially in confined spaces.

Some further trials with dummy men were performed at Operation Antler and are fully reported in Reference (6). These trials were carried out out for Antler Round 2 (about 5 KT) and Round 3 (about 25 KT) on similar lines to the tests at Buffalo, although in the Antler tests some additional dummies were exposed in Daimler Scout Cars (Round 2) and Champ Vehicles (Round 3). The following conclusions are given:-

(a) The information obtained on the displacement of dummies by blast confirms and amplifies that obtained from Operation Buffalo.

(b) Damage to dummies was more severe in the area affected by the precursor blast wave of the balloon burst weapon of about 25 KT total yield, than would have been expected from results at similar peak static overpressures obtained from the tower burst weapon of about 5 KT total yield where no precursor was present. (It should be remembered that precursor conditions only occur when the blast is likely to be very severe in any case).

(c) The conclusion reached after Operation Buffalo, that the best position for a man caught in the open when struck by a blast wave is prone and facing the blast, was confirmed.

(d) The wearing of a steel helmet with the strap under the chin is likely to lead to neck injury if the wearer is struck by a blast wave of peak static overpressure greater than 4 p.s.i.

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(6) Martin, A.R.F., A.W.R.E. Report T6/59, "The Effects of Blast on Dummies and Scout Cars."
(Confidential)

TABLE I - Damage Criteria for Light Earth Covered Structures

Structure	Damage	Peak Over-pressures (psi)	Remarks
Light steel arch surface shelter with 3 ft. of earth cover over crown. (10-0.141 inch gauge corrugated steel with a span of 20 to 25 ft.)	(Severe	25-35	Collapse
	(Moderate	20-25	Slight permanent deformation of arch
	(Light	10-15	Deformation of end walls, possible entrance-door damage.
Light reinforced concrete surface or underground shelter with 3 ft. minimum earth cover (2 to 3 inch thick panels with beams spaced at 4 ft. centres).	(Severe	25-35	Collapse
	(Moderate	15-30	Deformation, severe cracking and spalling of panels
	(Light	10-15	Cracking of panels, possible entrance door damage

Note. - A spread in peak overpressures for various degrees of damage is indicated to allow for differences in structural design, soil conditions, shape of earth mound, and orientation with respect to the blast wave. For defensive planning use the lower values.

9.3.2. Field Fortifications and Defences - Air blast is the controlling damage parameter for destruction of field fortifications such as unreinforced trenches and foxholes, revetted positions, and covered field shelters.

Un-reinforced Fortifications - The resistance of unrevetted trenches and foxholes to air blast is primarily dependent upon the soil characteristics, particularly the cohesive qualities of the soil.

Revetments - Revetted emplacements resist collapse at considerably greater overpressures than unrevetted emplacements. Light revetting materials such as chicken wire and burlap, or paste board, corrugated sheet metal, or plywood, when well supported, are fairly resistant to air blast. Light timber revetments are more resistant to air blast.

Overhead Cover - Covered fortifications that have their cover flush with ground level are subject primarily to downward pressures on the roof, whereas those fortifications having their cover above ground level are subjected also to drag loading, which tends to remove loose earth and disarrange and remove the cover structures. Entrances are usually the weakest point of blast resistance.

Other Damage Mechanisms - Severe air blast damage to revetted field fortifications occurs at ranges where damage due to direct ground shock and cratering alone is insignificant. However, for unrevetted foxholes and trenches in most soils, the direct ground shock produced by an underground burst contributes somewhat to the collapse. Superficial scorching of the wooden portions of field fortifications may also occur.

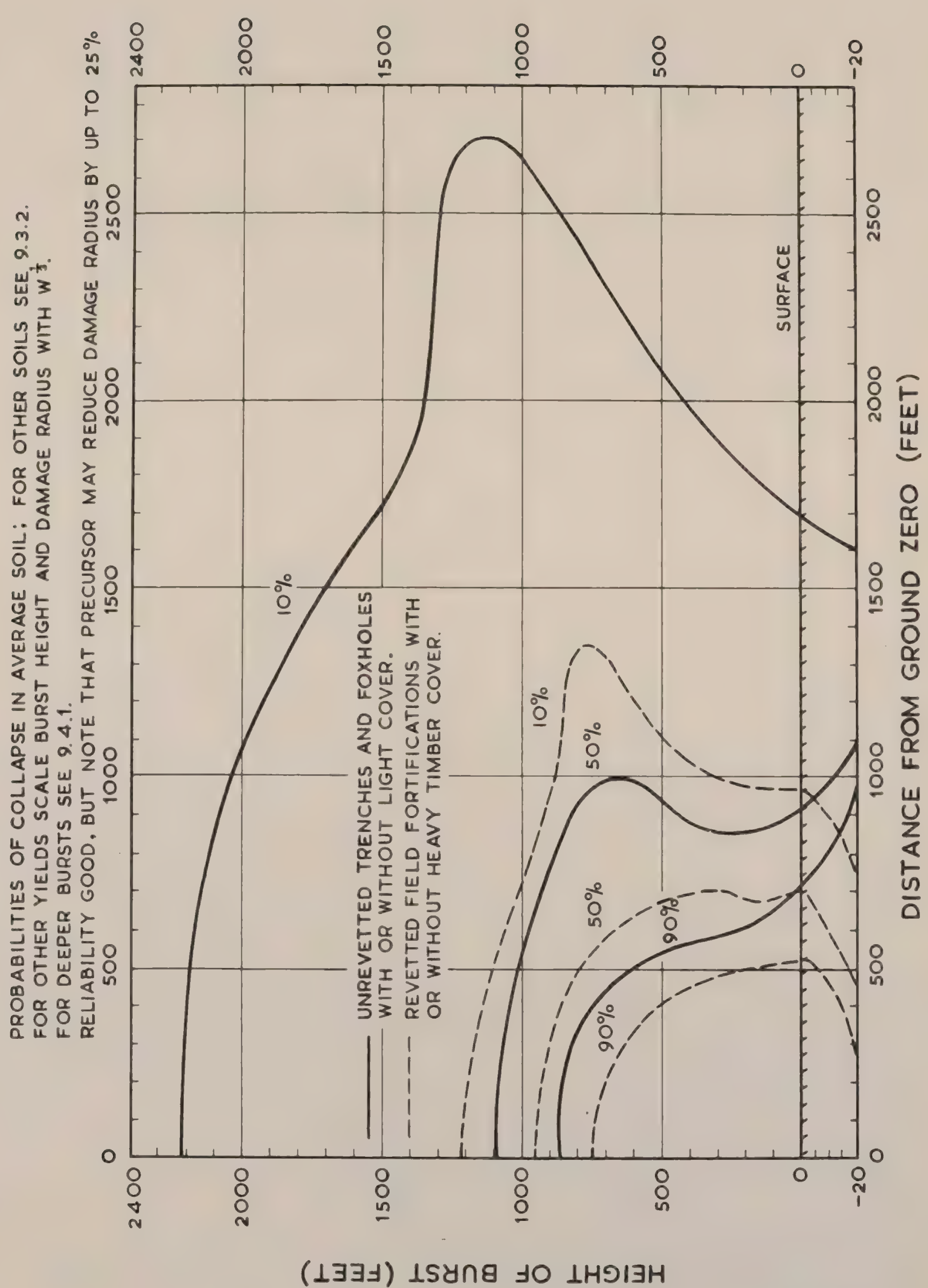
Damage Computations - The criteria for air blast damage are given as probabilities of causing collapse of the fortification. Figure 1 gives the height of burst versus ground range from a 1 KT burst for damage in average soil to unrevetted trenches and foxholes with or without light cover, and rivetted field fortifications with or without heavy timber cover. The given damage ranges are reduced in cohesive soils and increased in cohesion soils. If a precursor is expected, ranges may be as much as 25% less than those shown.

To obtain heights of burst and distances for yields other than 1 KT, use the scaling law -

$$\frac{d_1}{d_2} = \frac{W_1^{\frac{1}{3}}}{W_2^{\frac{1}{3}}} = \frac{h_1}{h_2}$$

Where d_1 and h_1 are ground distance and height of burst for yield W_1 KT and d_2 and h_2 are ground distance and height of burst for yield W_2 KT.

NOTE: For damage to barbed wire defences see Section 9.4.1.



DAMAGE TO FIELD DEFENCES. 1 KT.

9.4. Military Field Equipment

9.4.1. Introduction

Damage Mechanisms - Military field equipment targets are for the most part small, rugged, and free to move, and as such are primarily sensitive to the drag forces associated with the blast wave. Under some circumstances however, such as when items are shielded from drag forces or lie in the early regular reflection region, crushing by peak blast wave overpressures may be important. The drag forces tend to displace and to tumble targets of this type, and in the process, to damage them. Direct thermal damage to field equipment in general is not of importance; however, for certain items such as POL dumps, fire effects are important and are treated below. Secondary fire hazards from vegetation are not considered in this section.

Damage levels and definitions - Many factors must be considered in the selection of damage criteria for military field equipment targets. Among these are orientation of the item of equipment with respect to ground zero, orientation of the blast wave with respect to surface, i.e. whether the item is in the regular or in the Mach. region; shielding effects; the nature of the particulate matter in the blast wave; the presence or lack of flammable materials; the magnitude of the blast forces.

To simplify the presentation of damage criteria for blast effects in the following paragraphs, a height of burst versus ground range method of presentation for various levels of damage is used. The levels of damage are defined as follows:-

Severe that damage which is sufficient to prevent the accomplishment of any useful military function and the repair of which is essentially important without removal to a major repair facility.

Moderate that damage which is sufficient to prevent any military use until some repairs are effected.

Light that damage which does not seriously interfere with immediate military operations but necessitates some repair to restore the item to complete military usefulness.

Damage Probabilities - Specific examples of the types of damage associated with a given level of damage are included for each major item of equipment. Distances shown for moderate damage are the distances for which the probability of the damage occurring is 50%, and in some cases where the data permits, 10%. Distances shown for severe damage are those for which the probability of damage occurring is 50%, and in some cases where sufficient data is available, 90% and 10%. For light damage the distances are those for which the probability of damage is 10%. It is intended that the light damage curve and the moderate curve for 10% probability should be used to indicate approximate limits of damage, and thus may be of value in determining how close equipment may be placed to friendly bursts without endangering the combat usefulness of that equipment. It is assumed that for all damage curves, unless stated otherwise, that the items of equipment are oriented in a random fashion with respect to ground zero and lie unshielded on fairly level terrain. A discussion on shielding effects is given below.

Terrain and Topographrical Effects - The damage curves presented are the result of a great many exposures of military equipment to full-scale tests, and it is believed that the reliability of the data for a great variety of terrains is excellent. However, for bombs which are expected to produce a precursor over a terrain which yields no dust, the distances at which a given level of damage occurs may be somewhat less than indicated. Until further evidence is available however, it is recommended that the criteria shown be used for all types of surface.

Local topography may have considerable effect on the characteristics of the blast wave. In general, these result in an increase in damage for military field equipment located on the side of a hill facing towards the blast, and a decrease in damage for equipment located on the side facing away from the blast, compared with the damage at the same range on level terrain. No quantitative statement can be made at present as to the accentuation on the front face or the decrease on the rear face. However, the modifications may be so great that offensively, if more targets are located on the rear slope of a hill with respect to a proposed burst point, serious consideration should be given to re-selecting the intended ground zero. Defensively, every advantage should be taken of natural terrain features which provide drag shielding for items of our own equipment.

Effects of 'digging in' The damage curves for military equipment are drawn for equipment in the open on fairly level terrain, fully exposed to the drag forces of the blast wave. By 'digging in' military equipment, the equipment is somewhat shielded from these drag forces. The amount of shielding depends upon the type of emplacement used for the item of interest. For example, a shallow, open pit as an emplacement for an artillery piece provides little drag shielding, whereas a deep pit provides much more effective shielding. In the former case, the damage curves as presented could be used for predicting damage. In the latter case however, the damage curves predict, for a given level of damage, distances much greater than those which would actually be experienced. In order to make estimates of the effects of drag shielding, the following rule should be used:- "For items of military equipment which are well dug in, reduce the severe damage level by 2, and the moderate level by 1, i.e. both Severe and Moderate damage become Light."

Severe damage extends to ground ranges up to 50% less than those shown for the original severe damage curve. 'Well dug in' implies that the item is completely below the surface, without overhead cover.

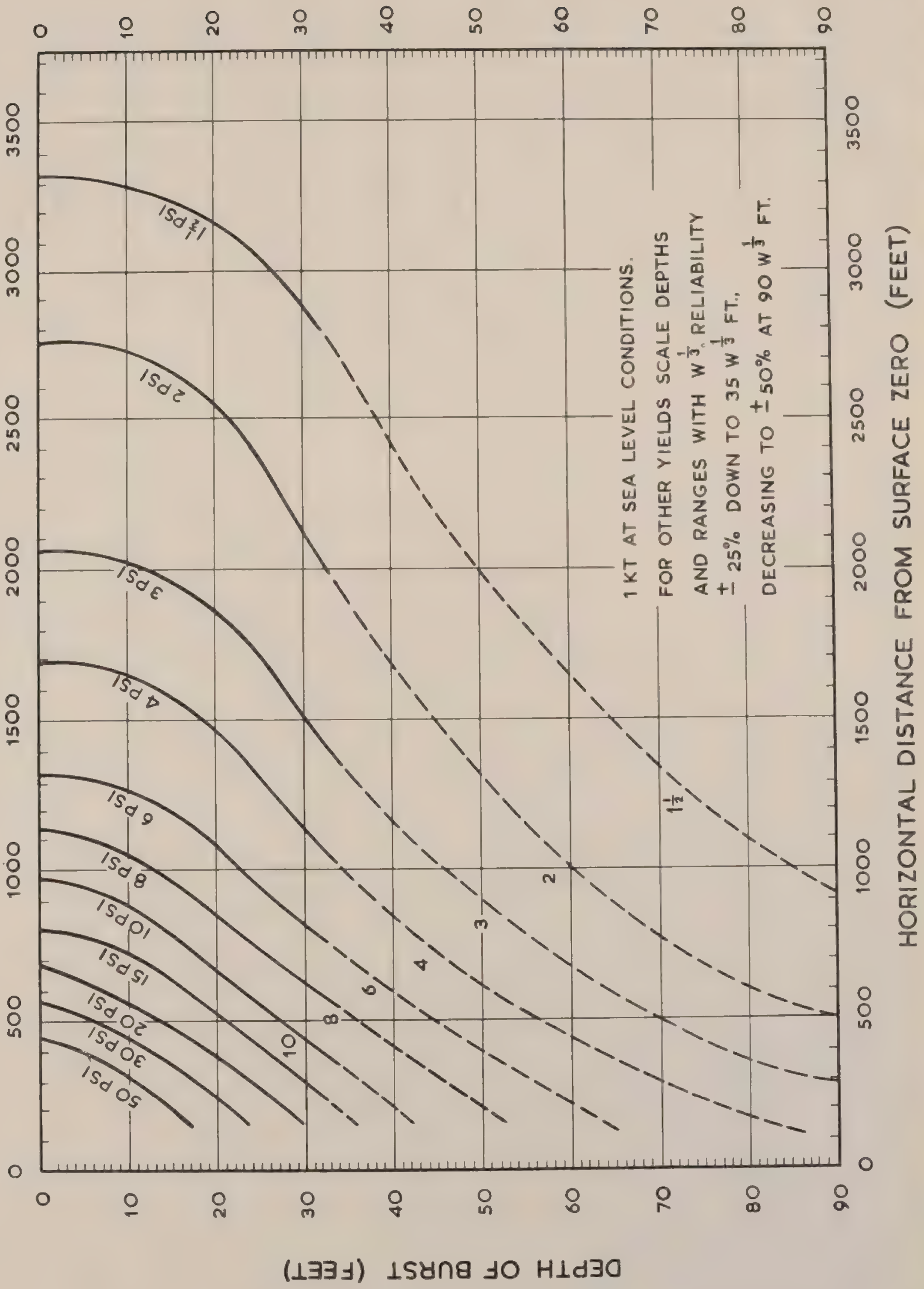
Sub Surface Bursts - It is to be noted that all damage curves of this section extend upwards from zero height of burst. To determine the distance to which a given item of equipment suffers a given level of damage from a sub surface burst, the curves of Figure 1 may be used. It is necessary to determine which curve (isopressure contour) of Figure 1 for a zero depth of burst, meets most closely the zero height of burst intercept of the damage curve of interest. This isopressure contour then serves as a continuation of the damage curve to determine distances for sub surface bursts. An example of this procedure is found accompanying Section 9.4.5, Figure 1.

Scaling - The scaling laws given with the damage curves of this Section have been checked for items of military equipment over a wide range of yields. It is believed that the laws are valid over a range of yields from 0.1 KT to 100 MT.

Other types of equipment - Criteria for many items of military field equipment not specifically mentioned in this Section can be determined by an examination of the damage curves that are presented. For example, heavy engineering heavy equipment such as bulldozers, graders, cranes and shovels are probably less vulnerable than a truck but more so than a tank. Therefore a reasonable estimate of the distance to which some items may be damaged can be arrived at by taking a mid-range value between that for trucks and that for tanks. Many types of military equipment are omitted; however, they may frequently be associated with other items of equipment that are specifically mentioned in the preceding paragraphs. An example of this is the pumping equipment normally associated with a POL dump.

Wire entanglements are very variable in vulnerability because of the many factors involved, such as the nature of the soil, the quality of the workmanship, and the depth of the picketing. For average soil conditions and U.S. military standards of construction, it has been determined that the criteria given in Section 9.4.4, Figure 1, can be used for estimating the distance to which it can be expected that wire entanglements are torn from their picketing or other supports. For double apron barbed wire fences use the telephone and switchboard curve of the above figure, and for concertina entanglements use the radio and electronic fire control instrument curve of the same figure.

Tents. Because of the large variability in anchorage, no definite criteria can be given. They are however, likely to fail in most cases at overpressures between 0.5 and 3 p.s.i.



DAMAGE RADIUS REDUCTIONS
FOR UNDERGROUND BURSTS

9.4.2. Tanks, Armoured Vehicles, Artillery, Ordnance Items, etc. - Tanks and artillery are about equally vulnerable except in the light damage category. Table I indicates which set of curves best fits the experimental data for other items of military ordnance. Examples are also given of damage levels for the various items. In all cases scaling to other yields is with $W^{\frac{1}{3}}$ for height of burst. and with $W^{0.4}$ for damage distances. Note that the curves apply to light and heavy vehicles; light, medium and heavy artillery; and light, medium and heavy tanks. The artillery curves include anti-aircraft artillery except for the electronic fire control equipment, which is discussed in Section 9.4.4. Thermal damage to ordnance equipment is generally superficial, such as scorching of paint and tyres. Canvas covers may be ignited from thermal radiation at energies ranging from 15 - 50 calories per sq. c.m. from a 1 KT burst, depending on composition, weight, impregnation, etc.

TABLE I - DAMAGE TO ORDNANCE ITEMS

Item	Damage Curves Most Closely Related	Examples of Severe Moderate and Light Damage
Tanks, all types	Sect.9.4.2. Fig.1	S- extensive turret, main armament and track damage - possible dismemberment. M- overturning, track and turret damage. L- antenna damage.
Artillery	Sect.9.4.2. Fig.1.	S- extensive recoil mechanism, wheel and trail damage, possible dismemberment. M- bent and twisted trails, some recoil mechanism danage, wheels may be torn off. L- sight glass breakage.
Mortars and recoil-less rifles	Sect.9.4.2. Fig.1 (for light damage use artillery curve)	S- Dismemberment. M - Twisted standards and mountings L- Sight breakage
Small arms and machine guns	Sect.9.4.2. Fig.1 (for light damage use artillery curve)	S- Dismemberment. M - Broken stocks, twisted and broken mountings. L - Cracked stocks
Rocket launchers	Sect.9.5.3. Fig.1	S-Torn to pieces. M - Twisted tube. L-Sight damage
LVT's and DUKW's (on land)	Sect.9.5.3. Fig.1	S- Great distortion and possible rupture of hull. M - Hull distortion, track damage. L - Glass breakage

9.4.3. Land Mines and Minefields Among the many parameters determining the effects of atomic detonations on minefields are type of mine, soil characteristics, mine spacing and depth of burial, and the characteristics of the blast wave. Methods of accounting for all of these parameters are not available for all types of mine. However, information is available on a number of mine types from which generalised criteria have been developed. Because mines are insensitive to thermal and nuclear radiation these effects are not treated in the discussion which follows.

Depth of Burial and Soil Type - In general, if the soil is not frozen and the depth of burial is not greater than about 2 ft., the criteria as given below are applicable for most soils normally encountered. There is at present no information available on the transmission of pressure through frozen soils, but it is believed that if the soil is frozen, no detonation of buried mines can be depended upon except in the region of cratering.

Sympatheric Detonation - Mines are usually spaced so that the pressures from the detonation of one mine do not sympathetically detonate adjacent mines. However, the additional overpressures in the blast wave from an atomic detonation may be sufficient to cause some sympathetic detonation if the spacing of the mines is close enough to be critical. Sufficiently large gaps in minefields halt this process, so that extensive clearance by sympathetic detonation cannot be depended upon. The criteria as given below do not include any sympathetic detonation effects.

Blast Wave Form - In general, land mines are sensitive to the rise time of the blast wave, i.e. if the rise time is long, greater pressures are needed to detonate a given mine than if the rise times are short. Long rise times are characteristic of the precursor zone. Therefore, in the criteria given below, two sets of data must be specified for each mine type depending upon whether or not the mine is expected to be in a precursor zone. For all bursts for pressures less than about 8 p.s.i. the criteria are the same for bursts which produce a precursor as for those which do not. This is also true for mines with fuzes which are insensitive to rise times.

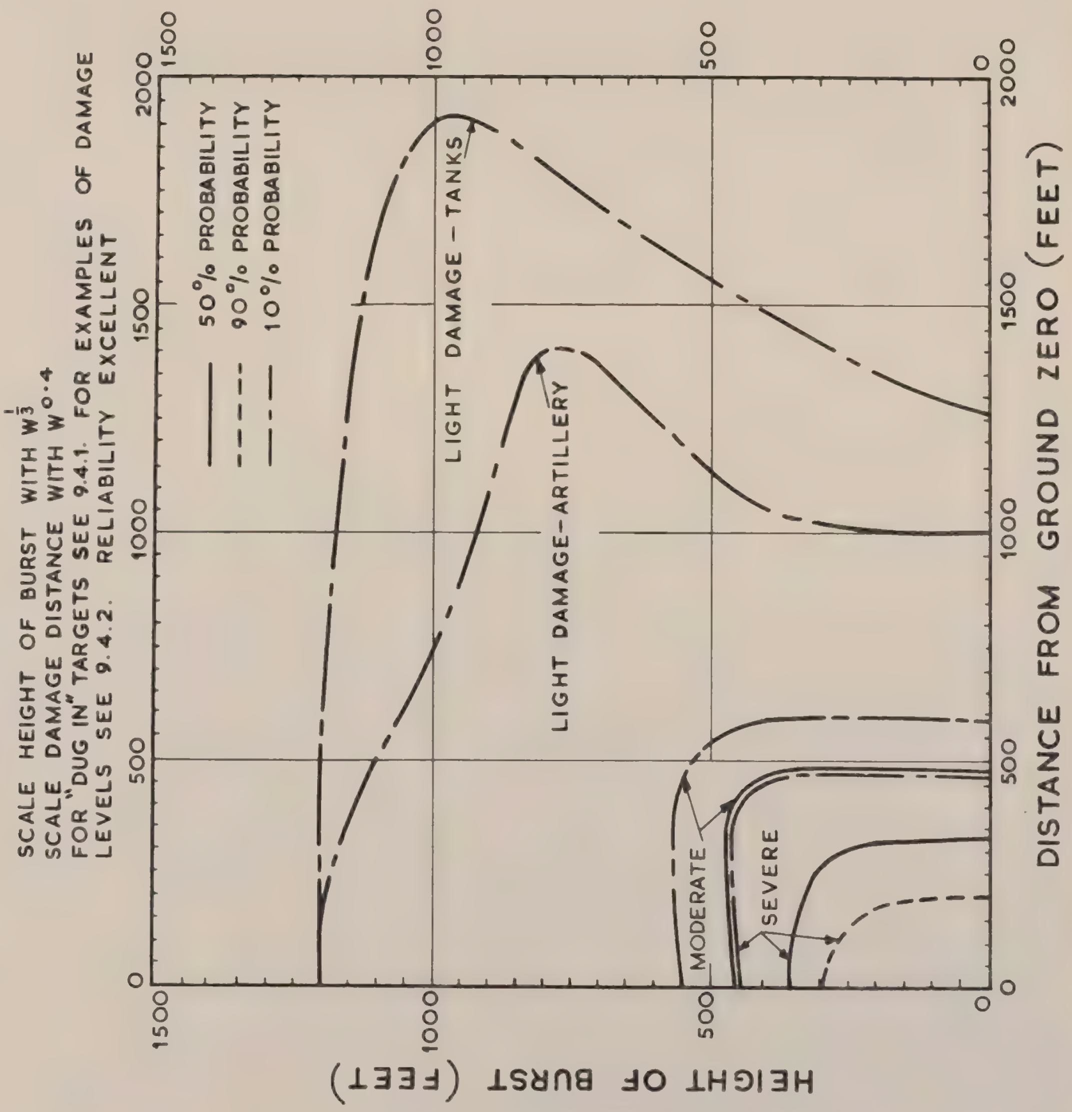
Mine Type - Although mines can be detonated by explosions acting on either the main explosive or on the more sensitive primer or boost, the overpressures required are so high that blast action on the pressure plates always controls. Detonation criteria presented in Table I are based on interpolation of test results on fuzed mines of the pressure-plate type. The Table does not apply to unfuzed mines, or to other mine types such as those with prong type fuzes or with double pressure activated pressure plates.

Criteria - In Table I are listed mines of various nations. For each mine criteria are given for 90% and for 10% detonations for precursor and non-precursor type blast waves, for depths of burial from 0" - 12" and from 12" - 24". Criteria for 50% probability of mine detonation are not given, since mine problems are concerned either with substantially complete clearance (90% probability), or with substantially little effect on the field (10% probability). Data of Table I are measurdd in the case of American mines, computed for the remainder. This Table is to be used in conjunction with the usual height of burst pressure curves for the appropriate surface conditons, the usual pressure scaling laws for yield being applicable.

TABLE I - Overpressures in p.s.i. Required to Detonate Various Mines

Country	Mine	0"-12" Depth of Burial				12"-24" Depth of Burial			
		Percent detonations - 90%		10%		90%		10%	
		Rise Time		Rise Time		Rise Time		Rise Time	
		Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
Belgium	PRB ND-49 Heavy Model A/T	20	30	17	25	30	30	25	25
	PRB ND-49 Light Model A/T	20	30	17	25	30	30	25	25
France	Model 1947 A/T	3	3	(*)	(*)	5	5	1.5	1.5
	Model 1948 A/T	15	20	10	15	20	20	15	15
	Model 1948 Plate Charge offset pressure	4	4	1.5	1.5	6	6	2	2
	Model 1951 Undetectable buried spider plate	5	5	2	2	7	7	3	3
	Model 1951 Shaped Charge, steel, offset pressure	4	4	1.5	1.5	6	6	2	2
	Model 1951 Shaped Charge, bakelite offset pressure	10	15	8	12	15	15	12	12
	Model 1948 A/P	4	4	1.5	1.5	6	6	2	2
Germany	TMi-35 A/T	4	4	1.5	1.5	6	6	2	2
	TMi-35 Steel A/T	4	4	1.5	1.5	6	6	2	2
	RMi-42 A/T	17	25	15	20	25	25	20	20
	SCHU A/P	2	2	(*)	(*)	3	3	(*)	(*)
Italy	CS 42/2 A/T	4	4	1.5	1.5	6	6	2	2
	CS 42/3 A/T	4	4	1.5	1.5	6	6	2	2
	CC 48 Shaped Charge A/T	7	7	3	3	9	9	5	5
	P-1 A/T	12	18	9	14	18	18	14	14
	P-2 A/T	12	18	9	14	18	18	14	14
	R A/P	2	2	(*)	(*)	3	3	(*)	(*)
	RM A/P	2	2	(*)	(*)	3	3	(*)	(*)
Turkey	4.4 A/T	7	7	3	3	9	9	5	5
	9.9 A/T	4	4	1.5	1.5	6	6	2	2
U.K.	Mark V (HC) - Buried Spider Plate	10	15	7	11	15	15	11	11
	Mark V (GS) - Buried Spider Plate	10	15	7	11	15	15	11	11
	No.5 Mk. 1 A/P	3	3	(*)	(*)	5	5	1.5	1.5
	No.75 Mk.II	7	7	3	3	9	9	5	5
U.S.A.	M-6 A/T	10	15	7	11	15	15	11	11
	M-7 A/T	35	35	30	30	35	35	30	30
	M-15 A/T	10	15	7	11	15	15	11	11
	M-14 A/P	7	7	3	3	9	9	5	5
	T-18 A/T	10	15	8	12	15	15	12	12
	T-20 A/P	3	3	(*)	(*)	5	5	1.5	1.5
U.S.S.R.	YAM-5 A/T	15	15	11	11	15	15	11	11
	YAM-5K A/T	14	14	10	10	14	14	10	10
	YAM-5M A/T	16	16	12	12	16	16	12	12
	YAM-5U A/T	15	15	11	11	15	15	11	11
	TMS-B A/T	5	5	3	3	8	8	4	4
	TMD-B A/T	15	15	11	11	15	15	11	11
	TM-41 A/T	25	35	20	30	35	35	30	30
	PMP-6 A/P	2	2	(*)	(*)	3	3	(*)	(*)
	PMD-7 A/P	2	2	(*)	(*)	3	3	(*)	(*)

* These mines may detonate in significant percentages at very low pressures (i.e. less than 1.5 p.s.i.



DAMAGE TO TANKS, FIELD ARTILLERY, ETC. 1K.T.

9.4.4 Signals and Electronic Equipment Including Field Radar - As the heat sensitive components of communications and electronic fire control equipment are generally shielded by the casings from thermal radiation, blast effects usually override thermal effects in cases where thermal effects alone might otherwise be significant. Radios, telephones, switchboards and electronic fire control equipment are very susceptible to damage by displacement. Figure 1 indicates the range at which damage is expected for these types of equipment. The curves are constructed on the assumption that the items of interest are unshielded from the effects of the blast wave and that the equipment is not intimately associated with other larger items. For example, a radio mounted in a truck is severely damaged if the truck is severely or moderately damaged, and a large switchboard installed in a building is severely damaged if the building collapses. Thus, if the equipment is intimately associated with other equipment, or with a structure, the criteria for damage to the other equipment or to the structure, should be used to determine the damage to the communication equipment. Note that only severe damage is indicated in Figure 1. Light damage for portable field radios consists of aerial damage, which is the basis for the tank light damage curve of Section 9.4.2.

Poled Telephone Routes - For estimating damage to telephone poles connected with wire, use Figure 2 (a) for arrays extending radially from ground zero, and Figure 2(b) in the case of transverse pole line arrays. Wire on poles is likely to be destroyed by the blast wave out to the limit of pole breakage. However, blast damage to wire on poles cannot be depended upon at greater distances.

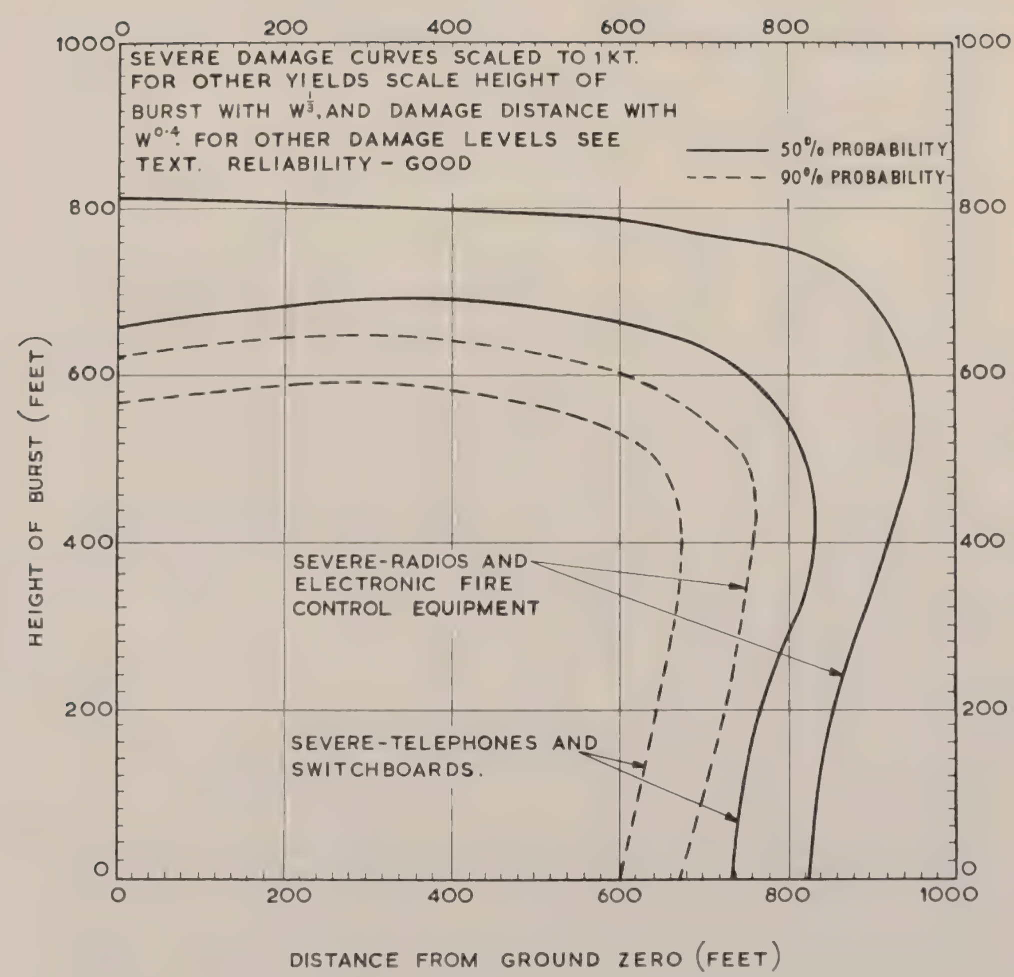
Scaling Laws - Scaling of damage distances for bursts of different heights and yields, in the case of Figure 1, follows the usual W^{2} scaling for height of burst, and $W^{0.4}$ scaling for damage distance, i.e.

$$\frac{h_1}{h_2} = \frac{W_1^{\frac{1}{3}}}{W_2^{\frac{1}{3}}} \quad \text{and} \quad \frac{d_1}{d_2} = \frac{W_1^{0.4}}{W_2^{0.4}}$$

Where h_1 = height of burst d_1 = damage distance for yield W_1

and h_2 = " " d_2 " " " " W_2

In the case of the poled telephone route data in Figures 2(a) and 2(b) there is of course, no need for scaling for yields below 1 MT, as values may be read directly from the curves, or by interpolation of iso-yield contours through the given intermediate points. For yields above 1 MT, scale both height of burst and damage distance with W^{3} from the 1 MT curve.



DAMAGE TO SIGNALS AND ELECTRONIC EQUIPMENT

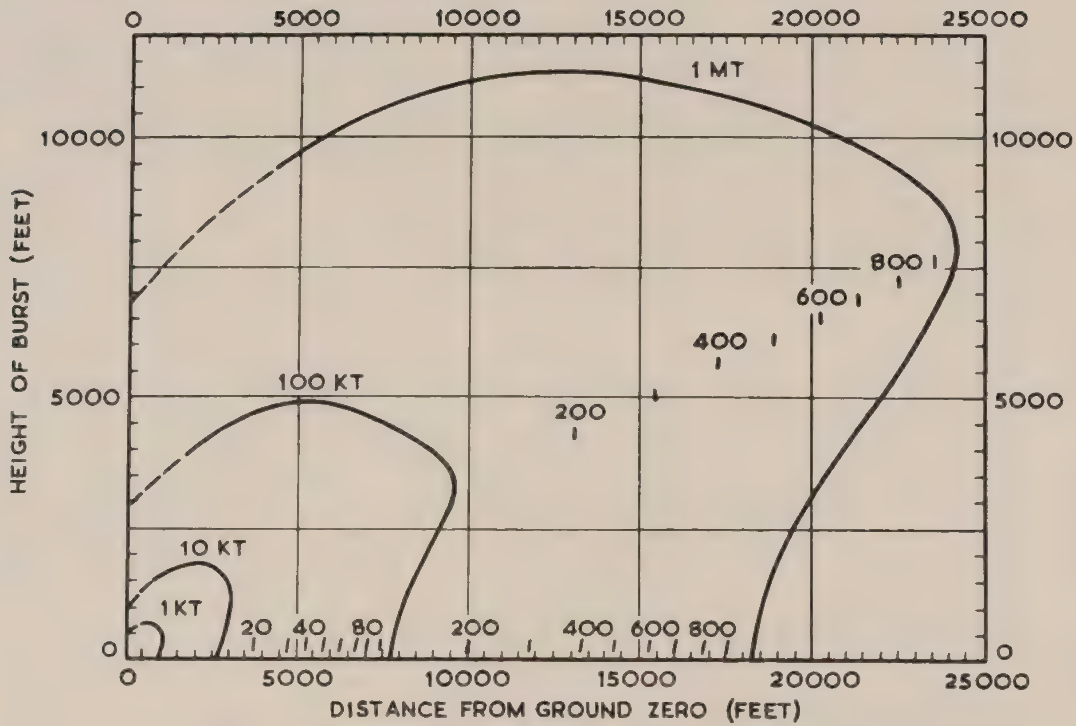


FIG. A. ROUTES RADIAL TO GROUND ZERO

FOR NATURE OF DAMAGE SEE TEXT.
SCALE 1 MT CURVE WITH $W^{\frac{1}{3}}$ FOR GREATER YIELDS.
RELIABILITY – GOOD

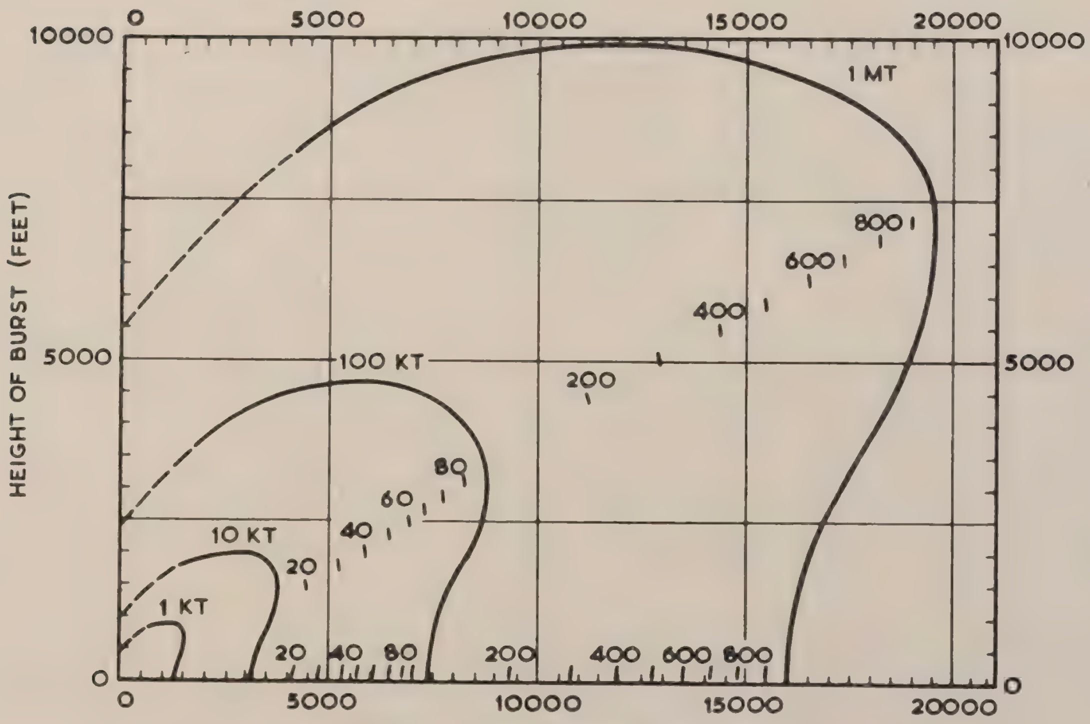


FIG. B. ROUTES TANGENTIAL TO GROUND ZERO

DAMAGE TO POLED TELEPHONE ROUTES

9.4.5. Supply Dumps - Height of burst curves are given in Figure 1 for blast damage to POL stored in 5 or 55 gallon drums (U.S.gallons), ammunition and rations in their standard packaging and other items normally packaged in small containers. The damage indicated refers to the packaging, and is caused by crushing, or by violent displacement and resultant tumbling, of the dump items. For POL, rupture of the packaging results in loss of the contents. However, this may not be the case for other items. Individual rounds of ammunition may be serviceable, even though thrown for great distances. This may also be true for rations. Note that only severe and light damage are indicated. Moderate damage is not considered, because the transition from severe to light damage is so abrupt for this type of target.

Damage Definitions:-

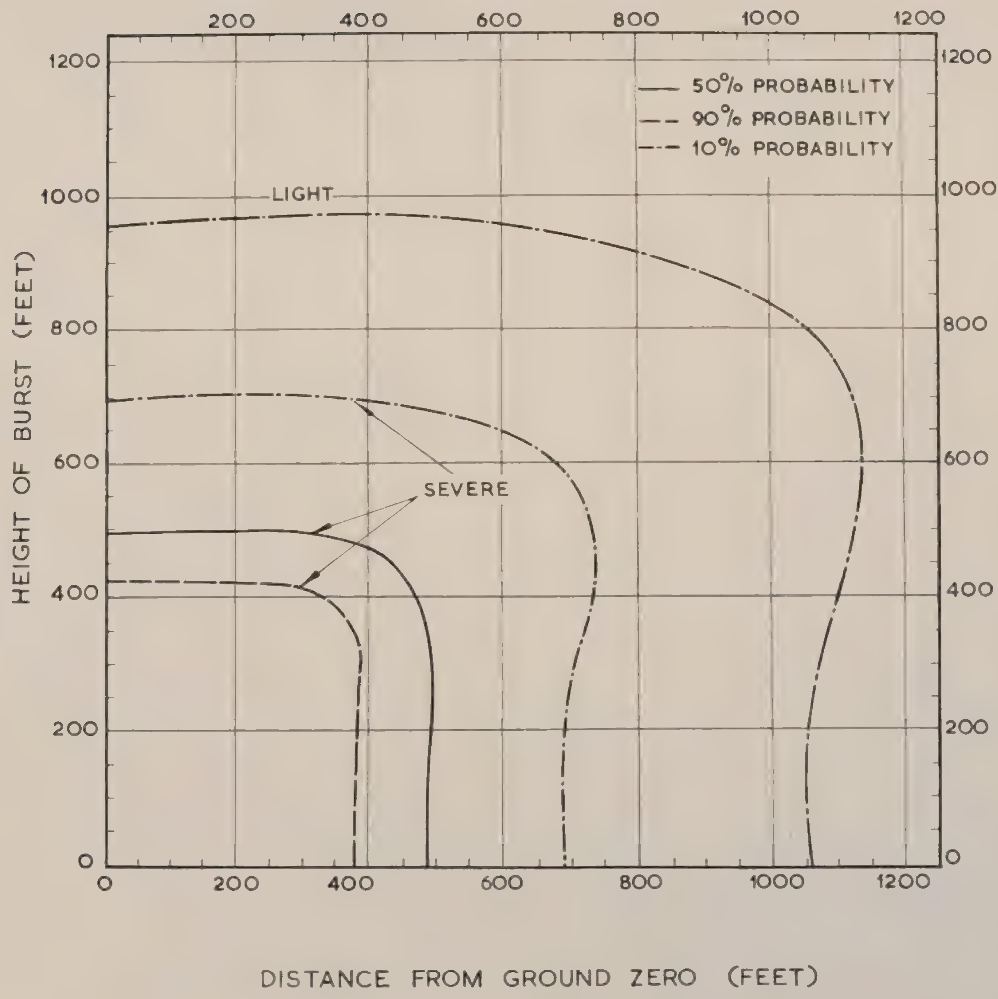
Severe - Rupture of casings, wide scattering, possible destruction of contents.

Light - Scattering of the cases with some cracking and some loss of contents.

Scaling for other yields, heights of burst, and damage distances follows the $W^{\overline{3}}$ rule for height of burst and $W^{0.4}$ for distance, as in the preceeding section.

Thermal Damage - Materials in supply dumps packaged in wooden or metal containers are not significantly affected by thermal radiation. However, serious fires may result in supply dumps from the ignition of kindling fuels such as newspaper, dry weeds and grass, and other litter comprised of thin organic materials. These primary ignitions may lead to fires in less combustible materials in the dumps which otherwise would not ignite. POL dumps are highly susceptible to fire under most conditions, owing to the establishment of ignitions in kindling fuels and the subsequent growth of these ignitions into fires, in either accidentally spilled fuels or in fuels spilled from containers ruptured by the blast. Energies required for ignition of various kindling fuels are given in Part 6, Chapter 5, Table 2. In the absence of kindling fuels it is considered unlikely that POL itself will be ignited, whether in open or closed containers or spilled on the ground.

SCALED TO 1 KT. FOR OTHER YIELDS SCALE HEIGHT OF BURST WITH $W^{\frac{1}{3}}$, DAMAGE DISTANCE WITH $W^{0.4}$. FOR "DUG IN" TARGETS OR FOR UNDERGROUND BURSTS SEE 9.4.1.
RELIABILITY – GOOD.



DAMAGE TO SUPPLY DUMPS

9.5. VEHICLES AND ROLLING STOCK

9.5.1. Railway Locomotives - Figure 1 gives iso-damage curves for severe, moderate and light damage to railway locomotives. Separate curves are given for side on and end on orientation at the higher damage levels. End on orientation refers to the blast wave striking the front or rear of the locomotive, and side on orientation refers to the blast wave striking either side of the locomotive. If it is not known what orientation exists, a mid-range between end on and side on values should be used for a given damage level. For surface or sub surface bursts, roadbeds are likely to be completely demolished out to a radius of 1.5 times the crater radius. Air bursts are relatively ineffective against roadbeds. For damage to structures normally associated with a marshalling yard, see Section 9.2. The damage curves of Figure 1 are drawn for a 50% damage probability. Examples of the damage levels used are -

Severe, intensive bending and twisting of end frame with overturning probable;

Moderate, bending or crushing of boiler and side and main rods with overturning possible;

Light, slight crushing of cab and glass breakage.

Scaling to other yields follows $W^{\frac{1}{3}}$ for height of burst and $W^{0.4}$ for damage distance, as in previous sections (e.g. 9.4.4.).

9.5.2. Railway Rolling Stock - Damage criteria for railway rolling stock are given in Figure 1. The rolling stock includes box wagons, tank wagons and open wagons. It is assumed that the wagons are randomly oriented with respect to ground zero, and that they are carrying a normal load. If the blast wave strikes the equipment side on, the damage will be greater than that indicated. If the wagons are empty, they are less vulnerable to vertical loads and more vulnerable to horizontal loads. Examples of the damage levels are,

Severe - extensive distortion, de-railment probable;

Moderate - sides of wagons demolished, some distortion of frame, possible de-railment;

Light - minor damage to sides and doors.

Box wagons moderately damaged could conceivably be used as flat wagons; however, as box wagons they would not be usable without extensive rebuilding. Scaling of Figure 1 for other heights of burst follows the $W^{\frac{1}{3}}$ rule, and for other damage distances, $W^{0.4}$. rule, as in previous sections (e.g. 9.4.4.)

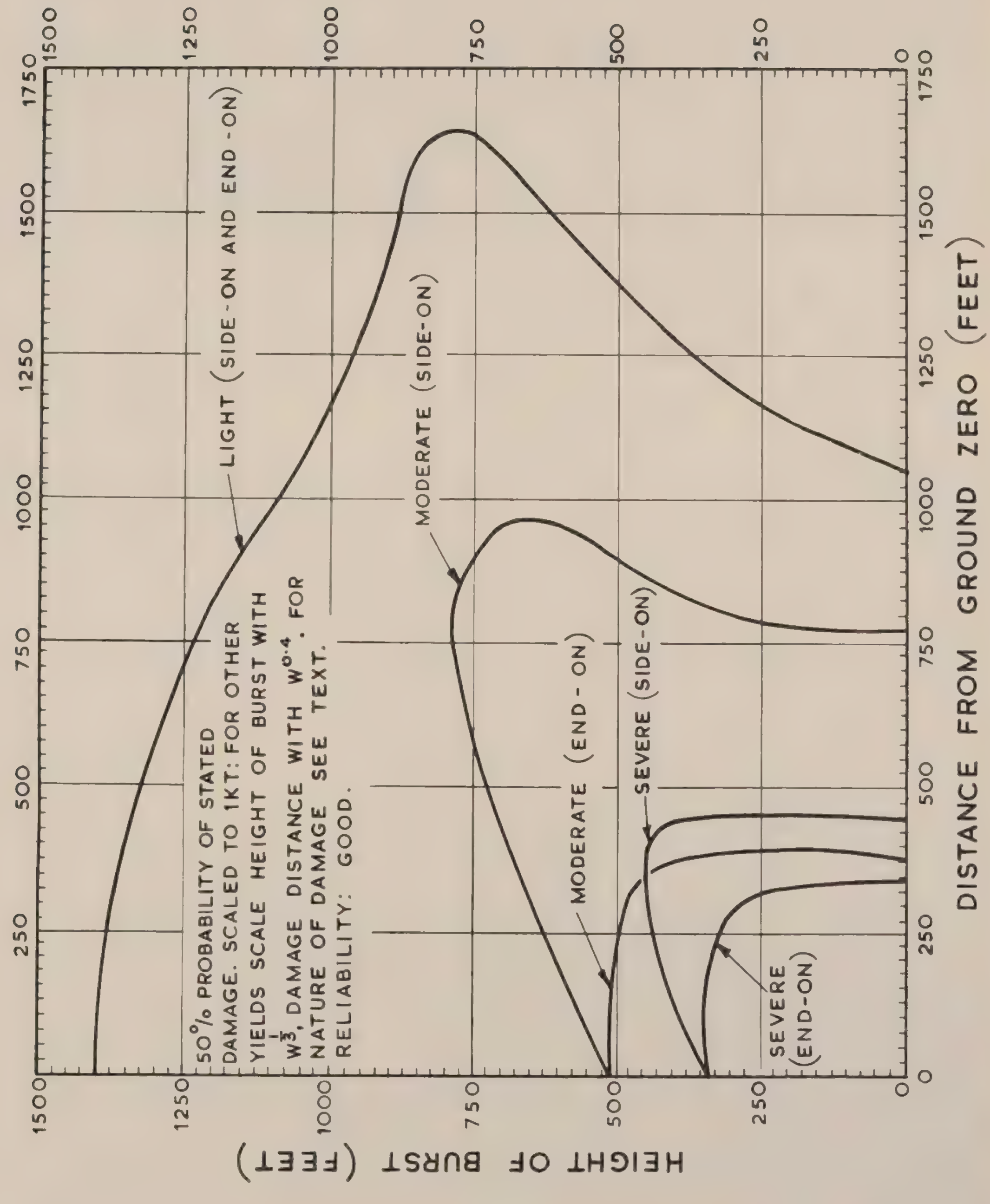
9.5.3. Motor Transport - The general remarks of Section 9.4.1. apply to motor transport and military vehicles. The curves of Figure 1 apply to all unarmoured military vehicles and also to civilian vehicles. They are also applicable to amphibian vehicles such as LVTs and DUKWs when on land. Typical examples of damage for which these curves are drawn are -

Severe - gross distortion of frame, complete disemberment possible, and great displacement;

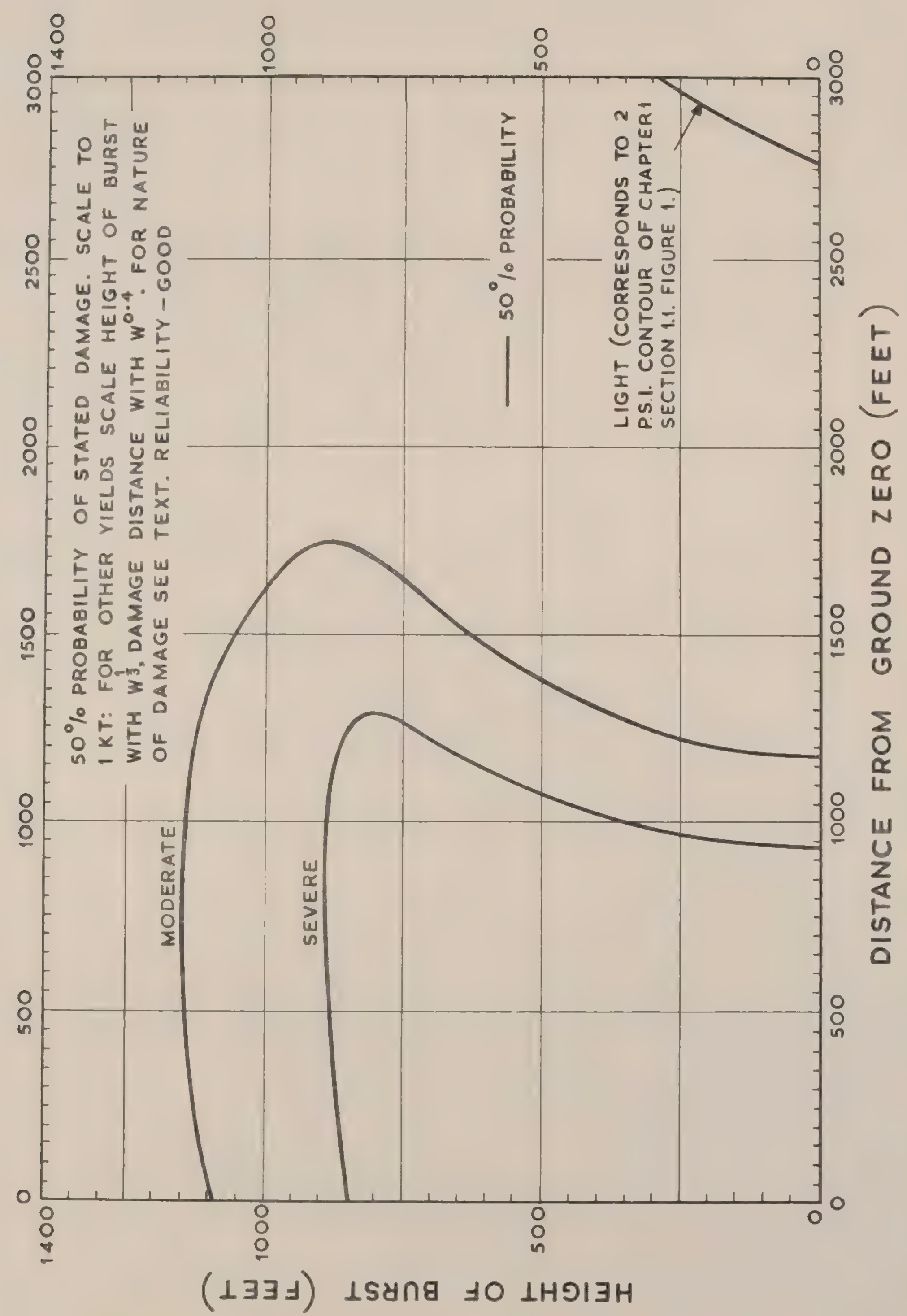
Moderate - some distortion of frame, engine mounts broken, wheels torn from vehicles, overturning probable;

Light - glass breakage, some ripping of mudguards is possible.

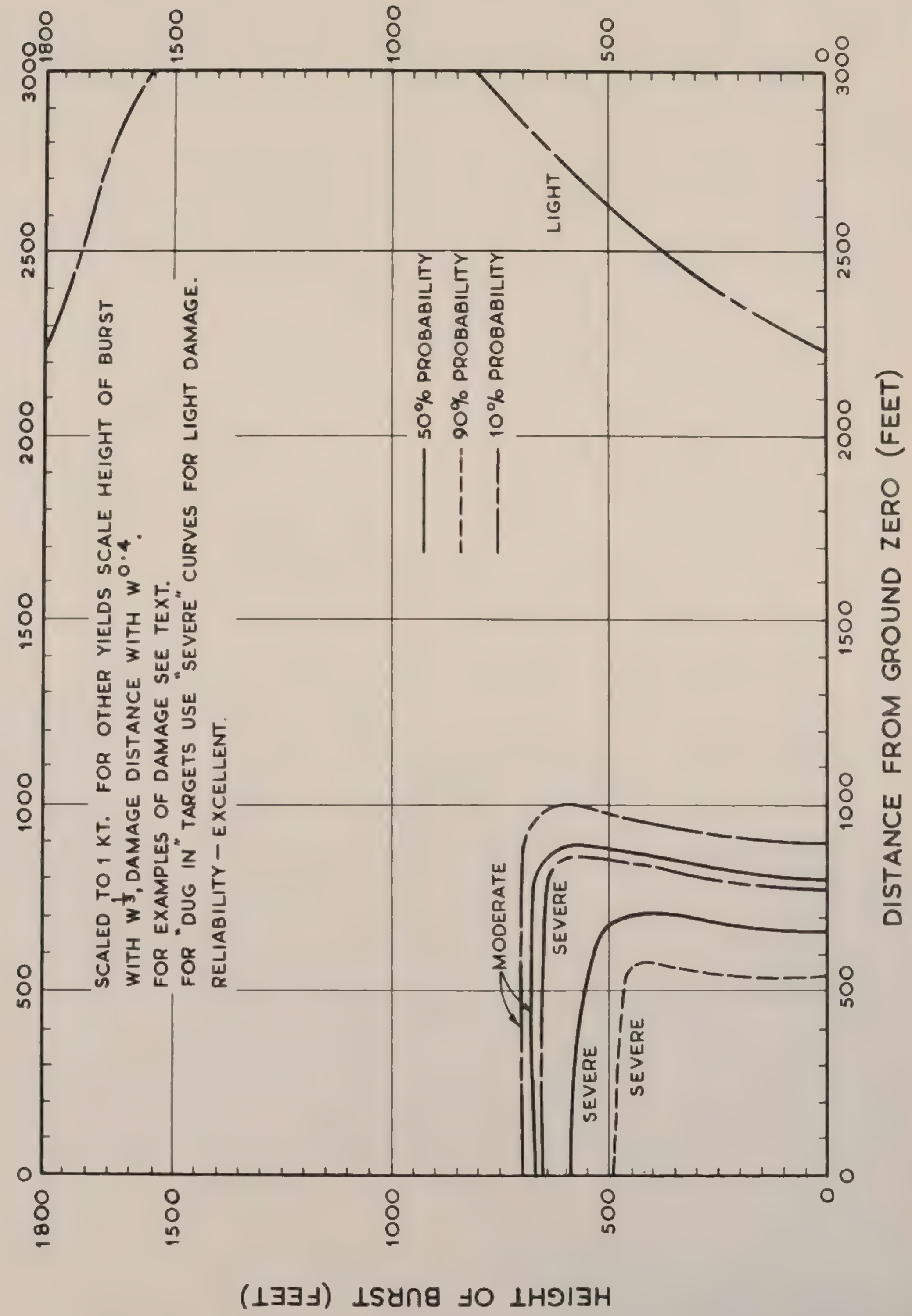
Scaling to other heights of burst follows the $W^{\frac{1}{3}}$ rule, and to other distances of damage the $W^{0.4}$ rule, as in previous sections (e.g. 9.4.4.)



DAMAGE TO LOCOMOTIVES



DAMAGE TO ROLLING STOCK



DAMAGE TO MOTOR TRANSPORT

9.6. AIRCRAFT

9.6.1. Nature of Damage to Aircraft

Aircraft components are generally constructed of rather lightweight structural elements, and because of this an aircraft is quite vulnerable to the forces imposed upon it by a blast wave. Enhanced overpressures resulting from reflection of the blast wave from the aircraft surface facing the blast may dish in skin panels and buckle stringers on that side. The blast wave overpressure, while not as large as the reflected overpressure, envelopes the aircraft and squeezes it, also dishing in panels and causing some buckling of stringers. Since the dimensions of aircraft components are usually small the diffraction process is short and does not produce any appreciable translational effect. The drag loading phase however, is relatively long and subjects an aircraft and its components to relatively large translational forces. (In aircraft loading parlance, dynamic or drag loading is usually referred to as 'gust loading'.) Since heating of the aircraft occurs more rapidly than conductive and convective cooling can take place, the thermal pulse produces stresses and may heat skin panels to such a degree that they are substantially weakened or even melted. Interior appointments and equipment, where directly exposed to thermal radiation, may ignite and cause fire damage to the aircraft structure itself.

9.6.2. Aircraft on the Ground - Air Blast Damage

The diffraction process and the drag phase have varying relative importance in producing damage to parked aircraft. In general, the diffraction process is of primary importance in the zones of light and moderate damage. In the zone of severe damage, the drag phase assumes more importance. Orientation of the aircraft has a considerable effect on damage. Revetments are expected to provide only slight blast shielding; they may, however, provide significant missile shielding. Damage to various types of parked aircraft may be estimated from the curves in Figures 1, 2 and 3. These curves are considered valid for all surface conditions. Because of the longer duration pulse from very large yield weapons, more increase in damage over that expected from small yields may result at the same blast wave overpressures. This effect is not well known quantitatively, and is not included in the damage curves. The curve in Figure 1 representing light damage to parked helicopters also estimates the range at which there is a 50% probability of grounding a hovering helicopter.

Thermal radiation - The aircraft components most easily destroyed by thermal energy are non-metallic parts such as the fabric-covered control surfaces, transparencies such as radomes and windows, de-icer boots, rubber and fabric seals, parachutes, cushions and headrests. Thermal damage to equipment of this type may be estimated from Part VI, Chapter 4, Tables 3 and 4. The primary aircraft components most vulnerable to thermal radiation are metal skin surfaces which are painted dark, since the dark paint produces a surface of high absorptivity. Proper shielding or direct modification can reduce the vulnerability to thermal radiation of both the primary and secondary components mentioned above. High performance aircraft generally have a thicker skin than lower performance aircraft, and therefore can withstand higher thermal inputs without damage. Moreover, highly polished bare metal surfaces have a reflectivity coefficient sufficiently high that damage due to thermal radiation is secondary to that caused by blast forces, except possibly, for weapons with yields in the megaton range.

Damage criteria - The isodamage curves of Figures 1, 2 and 3 apply to various types and orientations of parked aircraft. Figure 1 deals with parked helicopters, transport and liaison aircraft at random orientations. The 50% probability curves for moderate and severe damage may be used as 90% probability curves for the same degree of damage by scaling as indicated below, for a weapon of 4/10ths of the actual yield. Similarly, for conversion to 10% probability curves, scale in the same way, but using three times the actual yield. The damage definitions are as follows:-

Severe - that damage which requires at lease depot maintenance before the aircraft is fully operational.

Moderate - that damage which requires field maintenance before the aircraft is fully operational.

Light - that damage which does not prevent immediate operational use of the aircraft.

Scaling - Heights of burst and ground ranges for 50% probability of a given degree of damage may be scaled to other yields by multiplying these distances by the cube root of the yield. Resulting data may be used with good confidence in the kiloton range and with fair confidence in the megaton range. The isodamage curves in Figure 2 for randomly parked combat aircraft, and in Figure 3 for nose-on parked combat aircraft, may be adapted in a similar manner for other percentage probabilities of damage and yields of weapon. In the definition of severe and moderate damage levels 'combat worthy' replaces the word 'operational' for combat aircraft.

9.6.3. - Aircraft in Flight

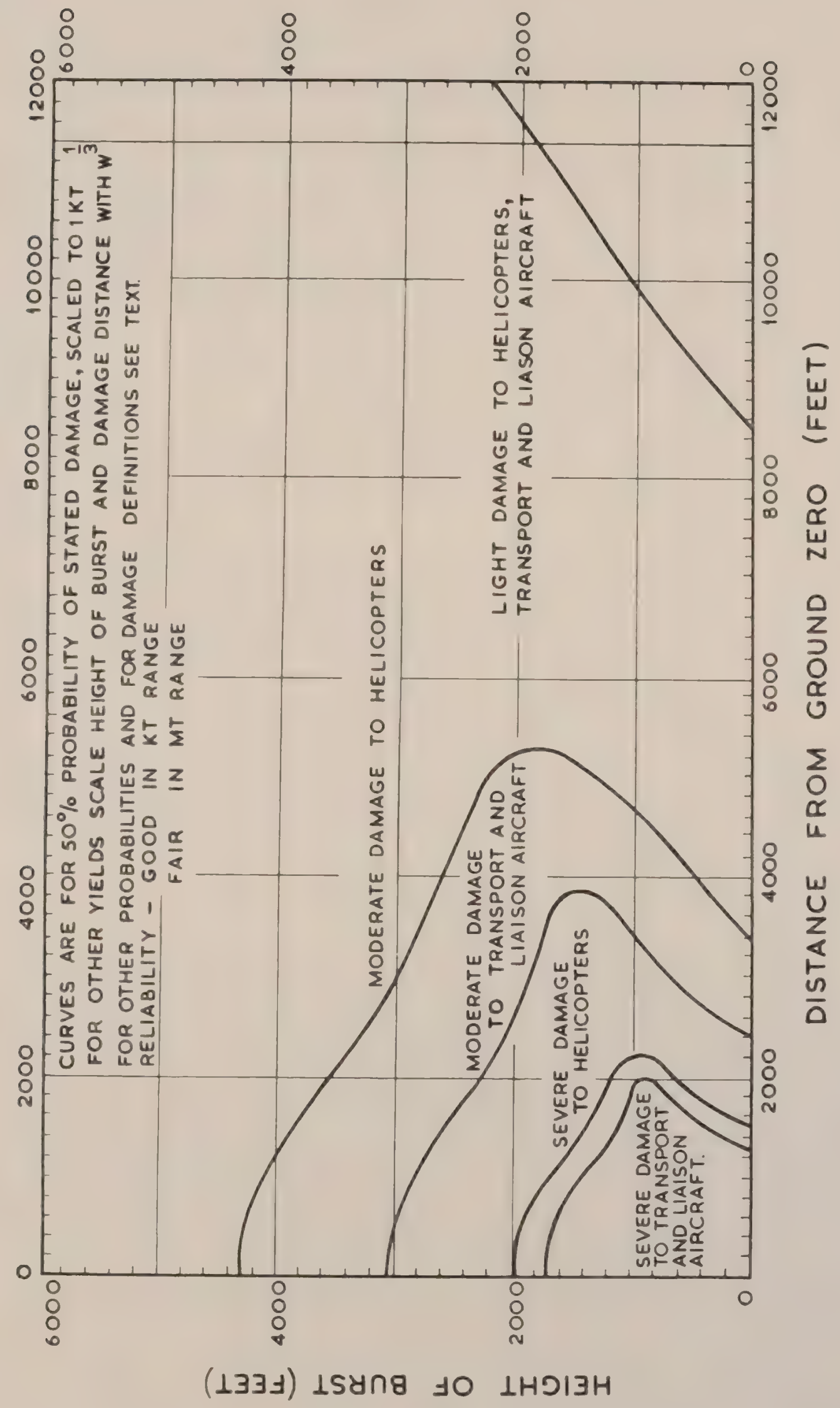
Air Blast - Since the response of airborne aircraft to blast loading is very complex, only a brief discussion is given in this manual. Where the diffraction process is the controlling factor, overpressure criteria are adequate for damage prediction. On the other hand, gust loading and the resulting response do not lend themselves to any simple criteria system of damage preduction. An airframe is a very complicated structure dynamically. Under certain conditions of gust loading, a given aircraft may fail structurally under a dynamic load of less magnitude than would cause static failure. Likewise, the same aircraft, under a different set of circumstances, may withstand a greater dynamic force than would cause failure under static loading conditions. Factors combining to influence aircraft response include true airspeed of the aircraft, the altitude of the aircraft and of the burst, the positive phase duration, the natural frequency of individual aircraft components, the weight and balance of the aircraft, the orientation and distance of the aircraft with respect to the burst, and the skill of the pilot. It must be emphasized that there is no unique scale relationship between one set of these variables and another, and that the relationship becomes even more complex for yields less than about 20 KT. Each particular problem must therefore be studied separately.

Thermal radiation - An incident thermal flux in excess of about 60 $cal/cm.^2$ is considered lethal for a conventional type aircraft. For small yields the range to which 60 $cal/cm.^2$ extends is usually exceeded by the lethal gust range. For aircraft with fabric control surfaces, dark painted metal surfaces of high absorptivity, or low flying aircraft capable of outrunning the destructive forces associated with the blast wave, thermal effects may exceed blast effects, even for low yields.

The degree of shielding from thermal radiation an aircraft affords its crew depends on the location of the burst relative to the aircraft, and the location of the crew within the aircraft. For a target in the air several different situations may arise, any one of which may lead to significant departures from the thermal energies predicted at a given slant range. Where the radiation traverses a path at altitudes greater than 10,000 ft. above the surface, the absorption and scattering effects decrease rapidly, with the result that observed thermal energies are greater than those calculated from the curves given in Part VI, Chapter 1. If the target is above the burst point, additional energy contributions are received by the target after reflection from the surface below. The effect is greatest with snow cover on the ground, and least over densely vegetated areas. If the target is beneath the burst the contribution of radiant energy from the ground is negligible in comparison with the energy received directly. For a burst below the target, with clouds above the target, the energy received by reflection from the cloud is negligible in comparison with the energy received directly. On the other hand, if the target is above the clouds, and the burst below, the clouds serve as a thermal shield. For a burst between the target and the cloud the situation is similar to the case of snow on the ground, since both snow and clouds are good reflectors.

Nuclear radiation - Since an aircraft is structurally light, its mass provides negligible shielding against nuclear radiation for the air crew.

Damage criteria - Figure 1 is a simplified diagram to illustrate, for several weapon yields, the general shape and order of magnitude of the volume about a typical bombardment type aircraft within which a nuclear detonation probably destroys it. This is a vertical cross section of the lethal gust envelope in the plane of symmetry through the longitudinal axis of the aircraft. Curves are given for yields between $\frac{1}{2}$ and 20 KT. For yields greater than 20 KT, the lethal radius from a burst in the aircraft plane of symmetry may be obtained by scaling the 20 KT envelope with $W^{\frac{1}{3}}$. Note that these curves are presented primarily to illustrate general shapes and magnitudes of lethal gust envelopes for bombardment type aircraft. It is NOT intended that numerical data derived be applied directly to any specific aircraft models. (Editor's Note. -It is believed that the original curves were derived for B.29 type of aircraft structures).



DAMAGE TO AIRCRAFT ON THE GROUND.
COMMUNICATIONS & TRANSPORT TYPES, RANDOM ORIENTATION

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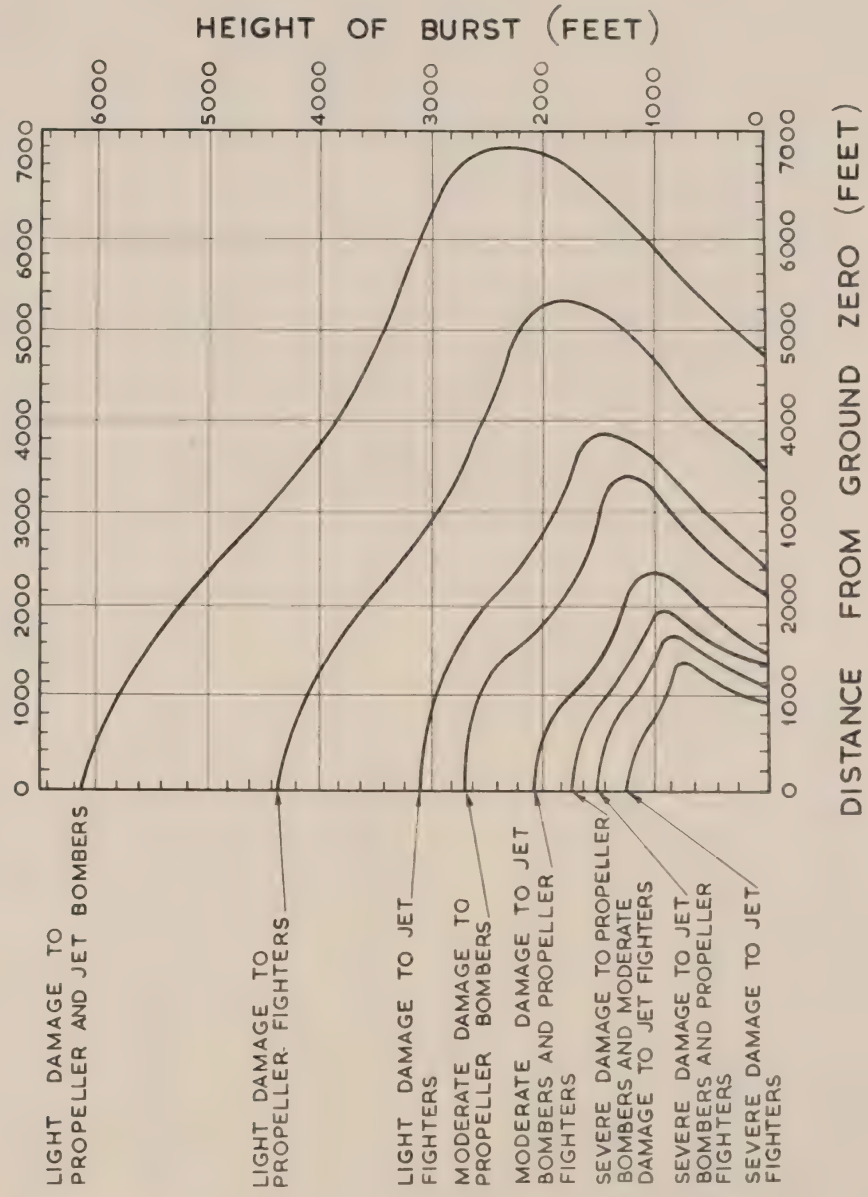
PART III
CHAPTER 9.
SECTION 9.6.2.
FIGURE 2.



DAMAGE TO AIRCRAFT ON THE GROUND.
COMBAT TYPES, RANDOM ORIENTATION

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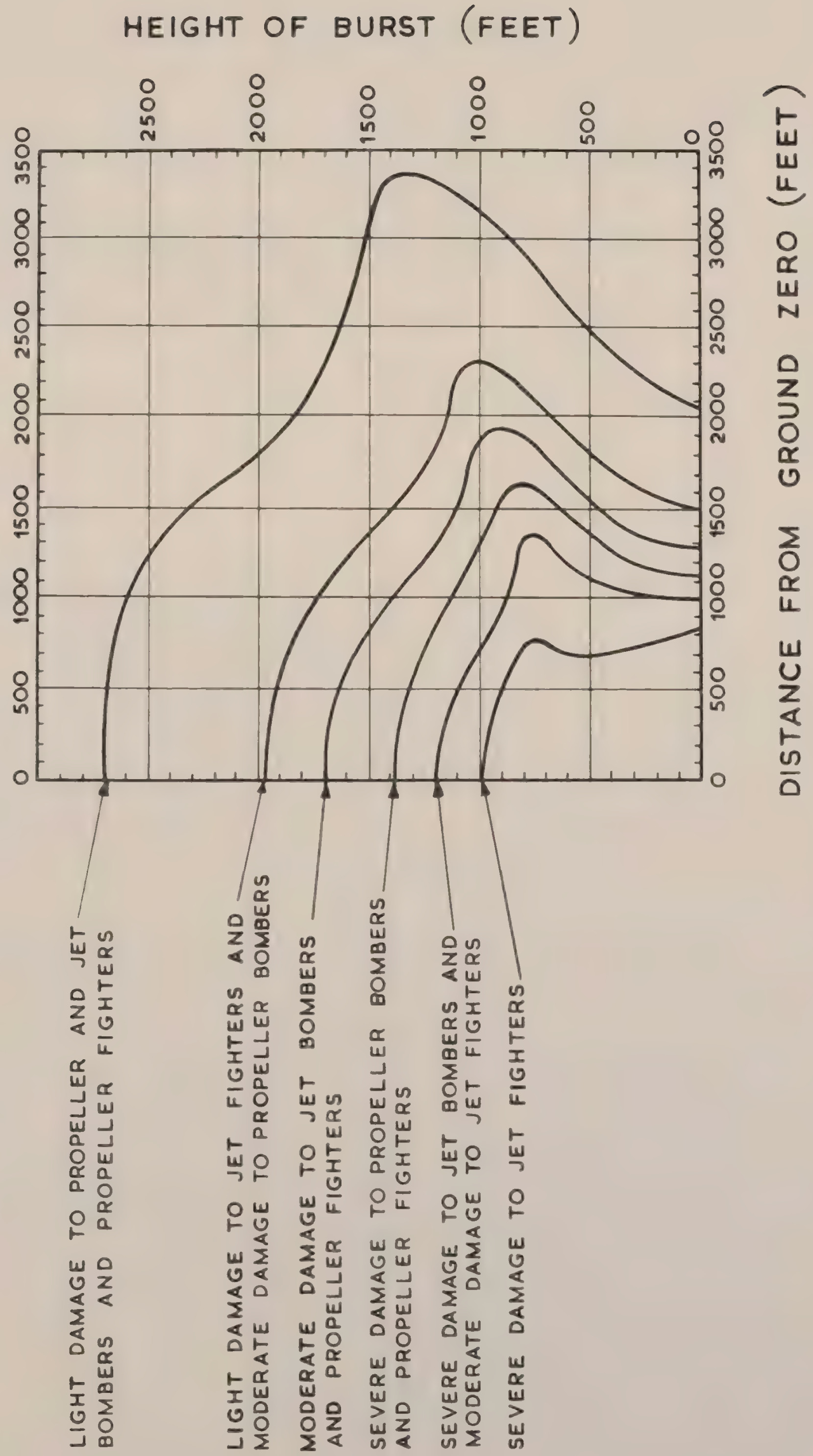
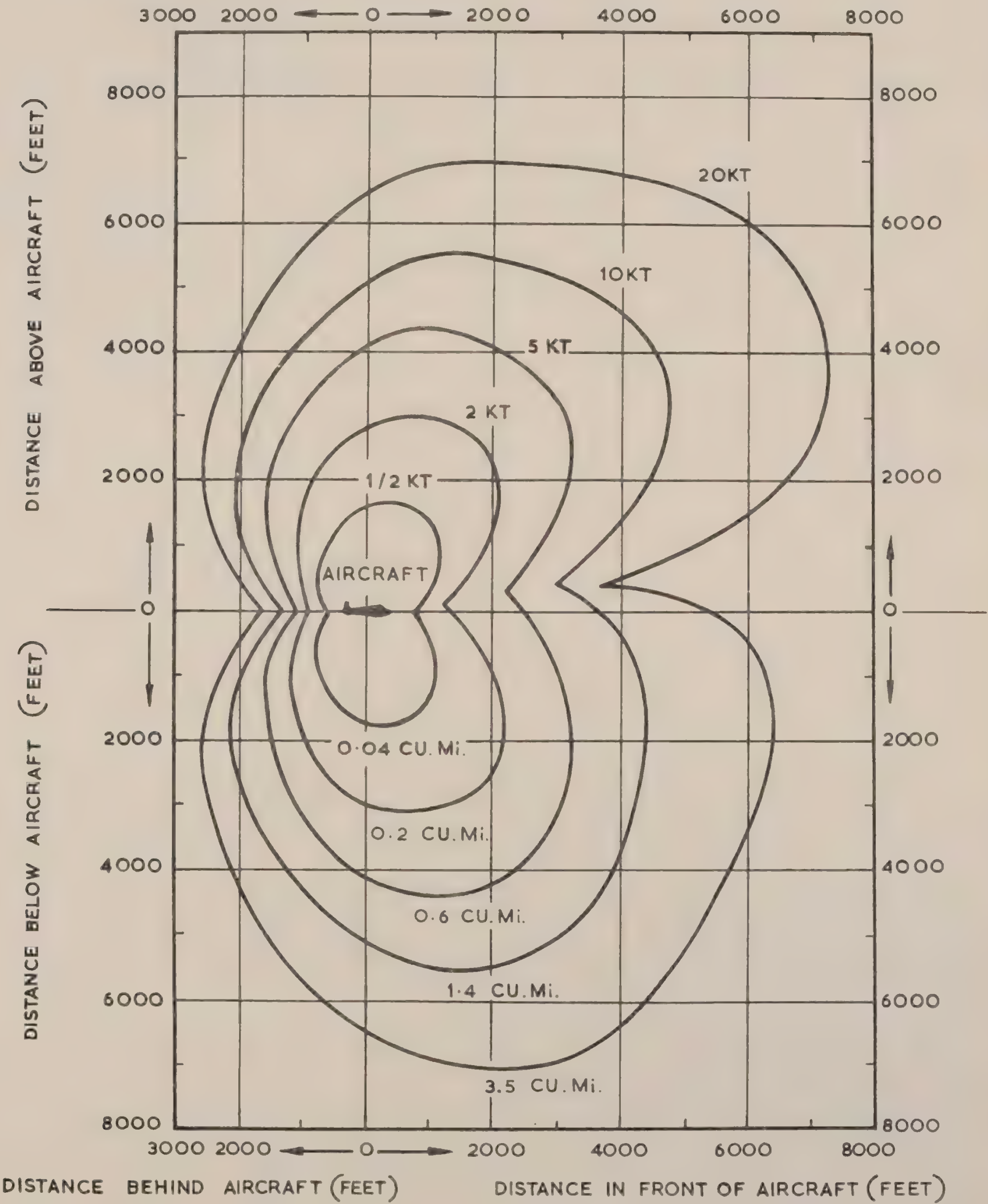


DAMAGE TO AIRCRAFT ON THE GROUND.
COMBAT TYPES, NOSE-ON ORIENTATION

THESE CURVES ARE PRESENTED PRIMARILY TO ILLUSTRATE GENERAL SHAPES AND MAGNITUDES OF LETHAL GUST ENVELOPES FOR BOMBER TYPE AIRCRAFT. IT IS NOT INTENDED THAT NUMERICAL DATA DERIVED BE APPLIED DIRECTLY TO ANY SPECIFIC AIRCRAFT MODELS. CUBE ROOT SCALING OF THE 20 KT CURVE WILL INDICATE APPROXIMATE ENVELOPES FOR LARGER YIELDS.



DAMAGE TO AIRCRAFT IN FLIGHT.
TYPICAL LETHAL GUST ENVELOPES

9.7. SHIPS AND MARITIME OBJECTS

9.7.1. Surface Vessels *

In addition to damage by water shock and surface waves, as described in Part V, mechanical damage to surface ships may be caused by air blast. Thermal damage to shipping is not considered an important factor in that it does not, of itself, cause sinking or immobilisation. As the depth of a burst is decreased, a transition from water shock to air blast as the controlling damage parameter occurs. Air blast is also the controlling damage parameter in the case of air bursts. Peak pressure is considered a satisfactory parameter for estimating damage to ships from air blast. A peak overpressure of 5 p.s.i. causes light damage to most types of surface ships. The peak overpressures required for severe damage vary from 25 p.s.i. for destroyers, to 45 p.s.i. for battleships; Figures 1 and 2 give damage ranges for a 1 KT burst. For heights of burst less than 600 ft., and depths of burst less than 800 ft., heights and distances scale with $W^{1/3}$ for other yields, although owing to the limited amount of data available only fair reliability can be assumed. The predictions also become less reliable at the shallower depths of burst. A tabulation of peak overpressure required to cause ship damage is given in Table I for use with burst heights greater than those shown in Figures 1 and 2. For these burst heights distances to which these overpressures extend are obtained from the usual height of burst/overpressure curves.

TABLE I - Surface Ship Peak Air Overpressure Damage Criteria

	Peak Air Overpressure (p.s.i.)		
	Severe	Moderate	Light
Aircraft Carriers	30	20	5
Battleships	45	25	5
Cruisers (heavy)	40	20	5
Cruisers (light) (AA)	30	20	5
Destroyers	25	15	5
Pontoons (for pier construction)	60	-	-
Transports	30	20	5
LSTs & Landing Craft and Landing Vehicles	25	15	5
Submarines (surfaced)	80	60	-

The damage levels are defined as follows:-

Severe - (Probable sinking). The ship is sunk or is damaged to the extent of requiring rebuilding.

Moderate - (Immobilisation) The ship requires extensive repairs. This includes damage to certain shock-sensitive components or to their foundations, such as propulsion machinery, boilers, and damage to interior equipment.

Light This category includes damage to electronic, electrical and mechanical equipment; however, the ship may still be able to operate effectively.

* Note: this information is of American origin, whereas British estimates (L.C.A.F.O.117/55) indicate somewhat greater damage radii corresponding to less severe pressure criteria.

9.7.2. Submarines

Data for surfaced submarines are given in Table I above; data for submerged submarines are given in Part V.

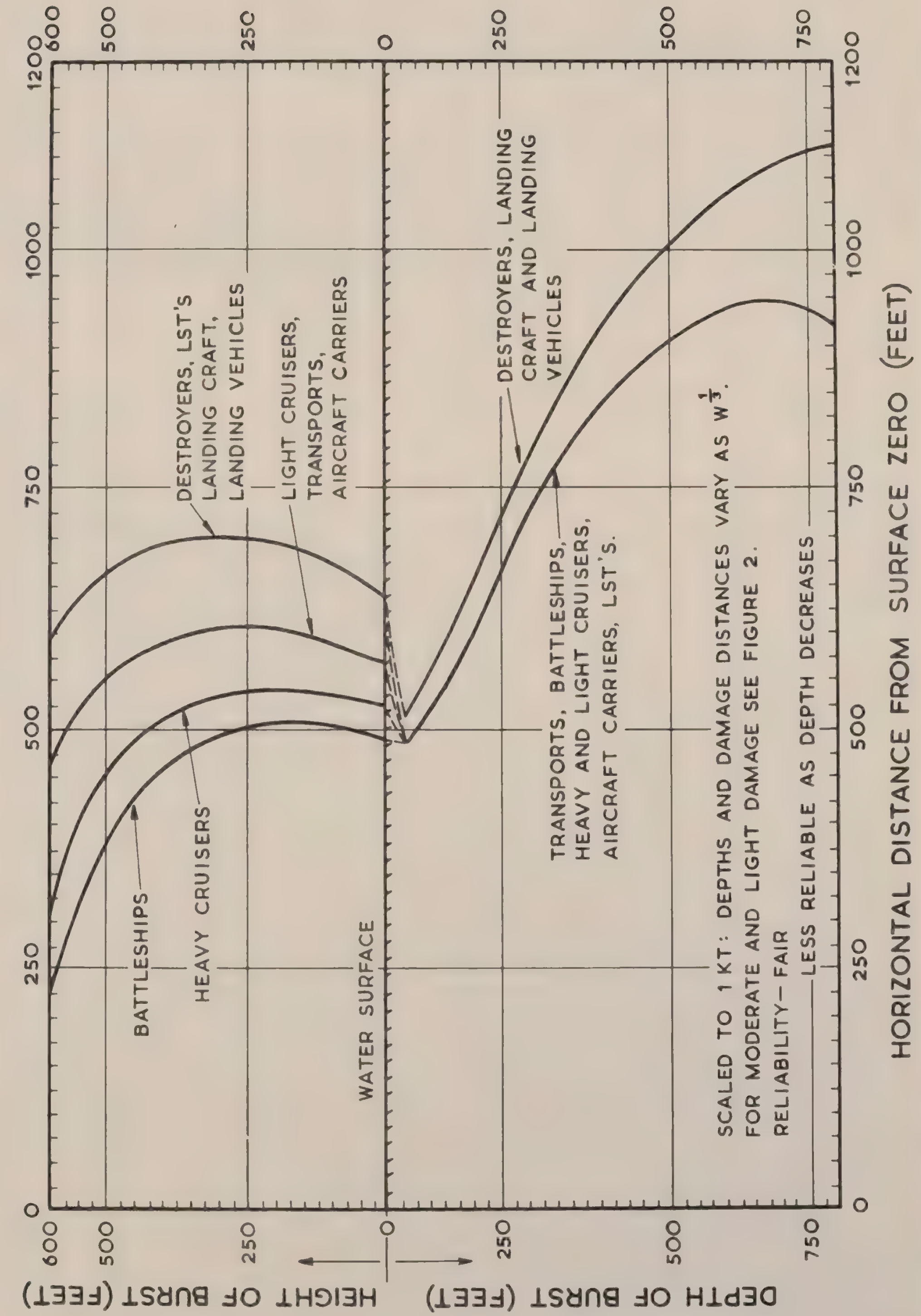
9.7.3. Dams, Lock Gates and Harbour Installations

Dams - A concrete gravity dam with the reservoir water level higher than about half dam height, is most vulnerable to an underwater burst, and damage under such conditions is therefore dealt with in Part V. A concrete gravity dam with the water reservoir level less than about half dam height is most vulnerable to a surface burst upstream from the dam. An air burst on the down stream side of the dam is the least effective method of breaching concrete gravity dams. Air blast from such a burst or from a burst on top of the dam is a primary damaging agent against powerhouse structures, and this should be analysed according to structural type as in Section 9.2. The damaging situations for lock gates and caissons are similar to those for gravity dams.

Harbour Installations - Air blast is the most important damage mechanism for most structures around a harbour. Air blast damage to surface structures is given in Section 9.2. For canal or river locks, where the water level around the gates is low, air blast is effective in making the locks inoperable by damage to the gates. Damage by cratering is dealt with in Part IV, and damage by water waves in Part V. Thermal radiation is no hazard to dams, but may start large fires by ignition of kindling material in dockside areas.

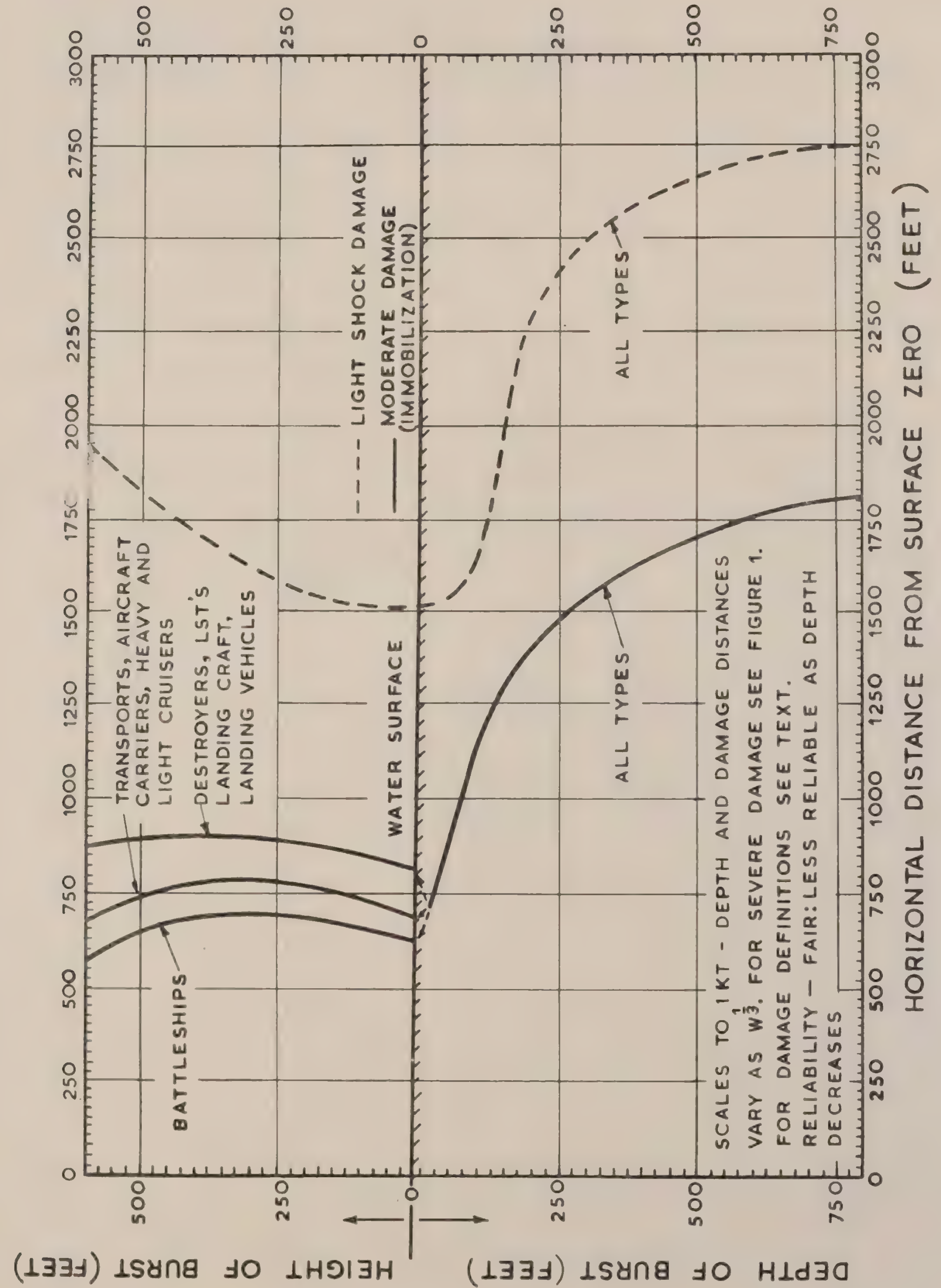
Note. Floating Bridges

Data on floating bridges are given in Section 9.2.8. above.



SEVERE DAMAGE TO SURFACE SHIPS
(PROBABLE SINKING)

SECRET ATOMIC



MODERATE AND LIGHT DAMAGE TO SURFACE SHIPS

SECRET ATOMIC

9.8 PERSONNEL

9.8.1. Injury by Blast Overpressure

The air blast from a nuclear detonation may cause casualties among human beings in two ways -

(a) Large pressure differences resulting from the blast wave overpressures may cause direct damage to lungs, abdominal organs, and other fluid or air-filled body organs. Translational forces on the human body may throw it for considerable distances.

(b) Personnel may become casualties through being injured or killed by the collapse of structures, by overturning and displacement of vehicles and equipment, or by missiles resulting from the air blast effects of the explosion.

The human body is relatively resistant to the crushing forces which result from air blast loading. Based on data obtained from high explosive detonations, it is estimated that of the order of several hundred p.s.i. peak overpressure is required to cause death in humans, provided no translational motion occurs. Severe injury may result at much lower pressures. Ear drum rupture may result at peak overpressures of 7 to 15 p.s.i., some cases have been known at 2-4 p.s.i. Ref(1). Early evacuation of all such cases will generally not be required, therefore the overall effectiveness of a military unit will not be hampered by the occurrence of these injuries. Both ear drum rupture and other bodily damage from this type of loading are largely dependent upon the characteristics of the shock front. If the rise time of the blast wave is long, the body organs are subjected to less severe pressure differences. Also, the body is able to adapt itself better to high overpressures when the pressure build-up time is long. Consequently, the probability of injury is reduced. Although little is known about the crushing effect of a long duration blast on the human body, increasing the duration probably lowers the peak pressure required for a given effect. Blast may be a major problem where the design of the structure permits build-up of the blast pressures through multiple reflections. Such a situation may be found in shelters, permanent type gun emplacements, or under similar circumstances where thermal and nuclear radiation are shielded out.

References

(1) Medical effects of Atomic Bombs in Japan.
Oughterson and Warren. U.S.Government Printing Office 1956.

9.8.2. Injuries Caused by Translational Motion

Bodily displacement of an individual exposed to a blast wave depends primarily on drag forces. Since the human body is relatively small, and the blast wave almost immediately envelopes it, the diffraction process is short. Displacement may be predicted with reasonable accuracy if the burst position, yield, and the orientation of the human body are known. The positive phase duration of the blast wave increases with increasing yield, and as a consequence the load causing translation is applied over a longer period of time. The translational force applied depends also on the exposed frontal surface area of the human body. An individual standing in the open is subjected to much larger forces than an individual lying on the ground surface. Adopting a prone position at the instant of an atomic bomb flash is effective in reducing the liklihood of injury from bodily displacement. Time of

arrival of the shock at a given overpressure increases with increasing yield and may be estimated from the data given in M.E.A.W. Chapter I, Data Sheet 1.8. The translational forces are reduced for an individual who is behind a building or in a shelter which is sufficiently resistant to withstand the blast forces. Foxholes afford almost complete protection against bodily displacement.

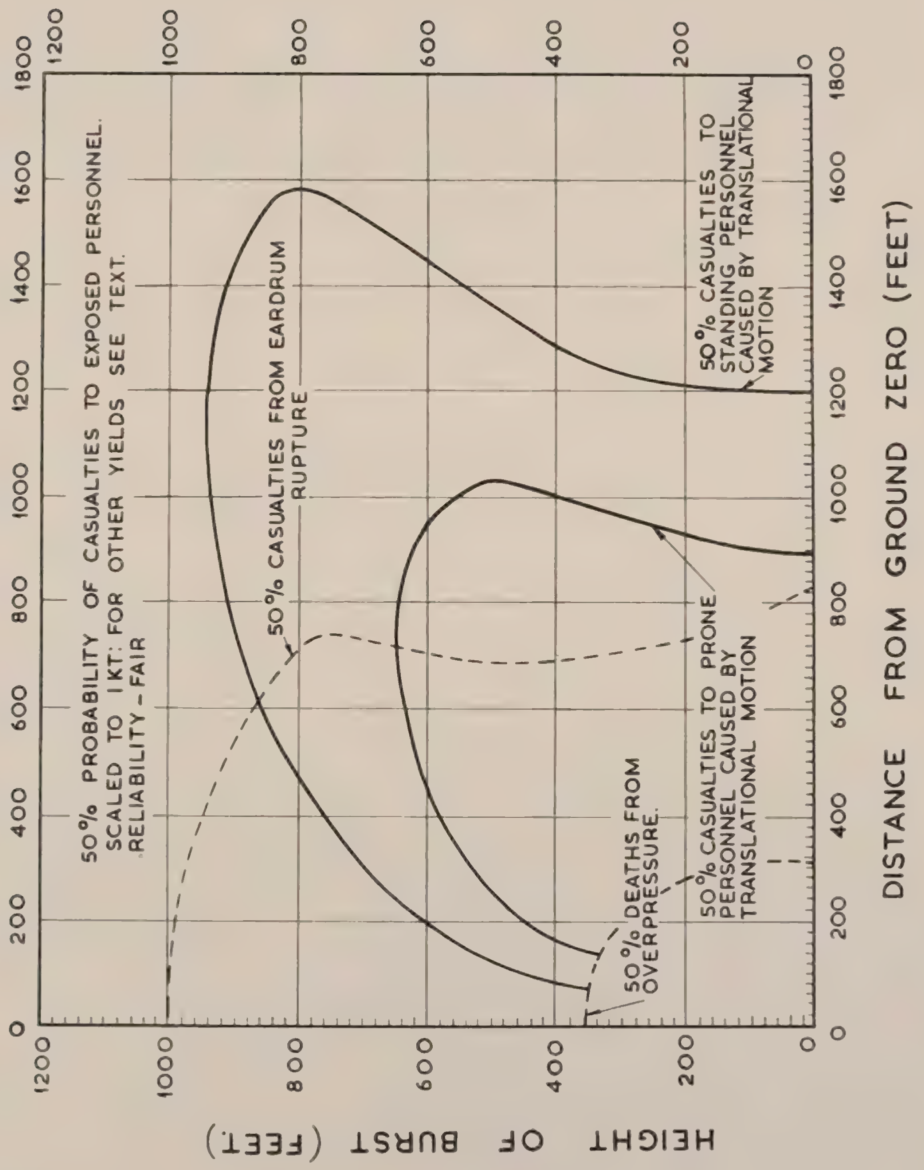
Criteria for Injury - Although no direct correlation is known between displacement and injury, it is reasonable to assume that some such relationship exists. The production of casualties from displacement depends almost completely on the nature of the impact. Some individuals may survive large displacement, whereas severe injury or death may occur with relatively small displacement. Severity of injury depends on the nature of the object or objects with which the displaced body collides and the nature of the impact, whether glancing or solid. Because increased yield results in increased positive phase duration and displacement, the probability of impact occurrences increases. The probability of impact occurrences likewise depends on the nature of the terrain and surface configuration. If solid impact occurs, it is estimated that body velocities of about 12 ft. per second produce serious injury approximately 50% of the time while collision at about 17 ft. per second results in about a 50% mortality. Figure 1 is a plot of height of burst against ground range at which 50% of standing and of prone personnel in the open are expected to become direct blast casualties. The curves are drawn for 1 KT, and may be scaled to other yields by multiplying the burst heights by the cube root of the yield and the ground distances by the 4/10th power of the yield in the case of the dashed curves. In the case of the full line curves both height and distance vary as the cube root of the weapon yield.

On account of the many possible variables the reliability of these curves can only be considered as fair.

Note. Some theoretical estimates for high yield weapons will be found in Reference (1)

References

(1) Estimate of some blast wind effects of Megaton bombs. A.W.R.E. Report No. E6/55
(Secret/Atomic/Discreet/Cleared for Canada).



DIRECT BLAST CASUALTIES TO PERSONNEL

9.8.3. Indirect Blast Injury: Casualty Estimates

Most blast casualties in cities are caused by damage to buildings. The occupants may be crushed, trapped, or struck by building materials projected by the blast. The number of casualties caused by a nuclear weapon will, of course, be dependent on the degree of protection afforded by the buildings and upon the extent to which advantage has been taken of such protection. For these reasons estimates of casualties cannot be expected to be more than rough guides to be used for Civil Defence planning.

Casualty figures from Hiroshima and Nagaski cannot be directly applied to Western conditions because of differences in house construction, and because the populations of these cities were not aware of the dangers to which they were exposed. But a method has been devised (1) in which the estimates of damage to British houses, (given by the British Mission to Japan), are used in conjunction with H.E. data from the last war on casualty rates in damaged houses to provide casualty rates for nuclear weapons.

The H.E. material was, of course, based on the high standard of rescue possible in the last war, and it has been necessary to adjust the casualty rates, since organised rescue of trapped occupants from the more severely damaged buildings will hardly be possible in nuclear war. The adjusted rates are given in Table I below, and can be used to derive casualty estimates.

TABLE I. CASUALTY RATES FOR OCCUPANTS OF BRITISH HOUSES

DAMAGE CATEGORY	KILLED	SERIOUSLY INJURED	LIGHTLY INJURED
A (> 15 p.s.i.)	90%	5%	1%
B (15-$7\frac{1}{2}$ p.s.i.)	40%	7%	5%
Cb($7\frac{1}{2}$-3 p.s.i.)	-	9%	6%
Ca(3-$1\frac{3}{4}$ p.s.i.)	-	2%	2%
D ($1\frac{3}{4}$-1 p.s.i.)	-	-	-

Note: (1) these casualty rates are related to blast effects only.
(2) typical 2-storey British houses assumed, with 9" or 11" brick walls.
(3) assumed that whole population is in such houses, taking best advantage of protection afforded.
(4) for definitions of damage categories see Section 9.1.3.

The pressure ranges for the various categories of damage given in Table I may be used in conjunction with the appropriate blast pressure curves to derive the extent of damage for any power of nuclear weapon.

American analysis of somewhat limited Japanese data for reinforced concrete structures suggests that on account of their much greater blast resistance, collapse is associated with almost 100% fatality. Moderate damage may be associated with 10% dead, 15% seriously and 20% lightly injured and light damage with 5%, 5% and 15% respectively. The corresponding damage distances are given in Section 9.2.2. Figure 2, and

Section 9.2.6, Figure 2. To make a good estimate of casualty production in other structures it is necessary to consider the type of structural damage that occurs and the characteristics of the resultant missiles. Glass breakage extends to considerably greater ranges than almost any other structural damage, and may be expected to produce large numbers of casualties at ranges where personnel are relatively safe from other effects, particularly for an unwarned population.

American estimates are that in cases of severe damage some 60% of the survivors may have to be extricated by rescue squads. Without rescue they may become fire or asphyxiation casualties, or in some cases be subjected to lethal doses of residual radiation.

A major cause of personnel casualties in exposed situations is flying missiles. These missiles have low velocities and many crushing injuries may be expected, in contrast to penetrating wounds caused by high velocity missiles. The missile density and characteristics are largely a function of the target. Where the target area is relatively clean and there is little material present subject to fragmentation and displacement, fewer injuries from missiles are expected in the open than from debris within structures at comparable distances. When the target complex presents many possible sources of missiles, this cannot be the case. Personnel in a prone position are less likely to be struck by flying missiles than those who remain standing. Those who succeed in getting into bunkers, foxholes, or in defilade, probably achieve almost complete protection from the flying missile hazard.

Personnel in vehicles may be injured as the result of the response of the vehicle to the blast forces. Padding where applicable, and the use of safety belts, helmets and harnesses virtually eliminates this source of casualties, at least within armoured vehicles. In the absence of these protective devices, serious lacerations may result from impact with sharp projections within the vehicle interior, but these vary greatly among different vehicles and at different positions within the same vehicle. Comparative numbers of casualties are almost impossible to assess in this respect, due to the many variables which are involved in the problem.

References

(1) Civil Defence Joint Planning Staff Paper C.D.J.P.S.(E.A.)(48)14 (Revised).

(2) Manual on the Effects of Atomic Weapons. A.W.R.E. (Secret/Atomic)

(3) Capabilities of Atomic Weapons A.F.S.W.P. (Secret/Atomic)

9.9. VEGETATION

9.9.1. Introduction

Although forests or tree stands may afford troops deployed in them significant protection against certain effects of atomic bomb detonation (e.g. thermal radiation), the forests themselves are quite vulnerable to some of these effects. Falling limbs and trees create a missile hazard, and the resultant debris on the forest floor may impede the movement of troops and most vehicles. In dry, windy weather, forest fires may be initiated by an atomic bomb detonation, with smoke and flame extending the range of hazardous effects from the bomb itself many times. Forest vulnerability depends on recent local weather history and upon the type of tree stand involved. Forest kindling fuels and types of stand are discussed in the paragraphs which follow from the blast damage point of view only. Thermal aspects of the problem are dealt with in Part VI.

9.9.2. Types of Forest Stand

For convenience in discussion of blast effects, forest stands are divided into three types.

Type I Stand - Improved natural or planted conifer forests of European Type.

These forests characteristically grow in regular blocks usually with definite borders. Tree spacing is uniform, with only small patches of ground visible through the canopy from above. Trees are of uniform height and nearly the same diameter. Viewed from above, the crown canopy appears smooth. Within the stand there usually are found low stumps resulting from thinning, clear lower stems as a result of pruning, and little or no underbrush, combining to give the interior of the stand a clear appearance and affording good visibility and easy passage into the forest.

Type II Stand - Naturally Occurring Unimproved Conifer Forests that developed under Unfavourable Growing Conditions -

Unfavourable growing conditions result from shallow rocky soil, deficiant annual rainfall, short growing season with unfavourable temperatures (i.e. higher altitudes or higher elevations), and unfavourable temperatures (i.e. higher altitudes or higher elevations), and unfavourable topography such as poorly drained flats or steep slopes. Random tree spacing is a characteristic, with all tree sizes represented. The crown canopy generally has an uneven appearance. Large stands often contain bare areas with irregular borders.

Type III Stand - All Broad Leaf Forests, and Naturally Occurring Unimproved Conifer Forests, that have developed under Favourable Growing Conditions -

Favourable growing conditions are associated with deep, generally rock-free soil; adequate annual rainfall; long growing season with favourable temperatures (i.e. middle latitudes and lower elevations); and favourable topography such as well-drained flats and moderate slopes, or along stream courses. Random tree-spacing is characteristic, with all tree sizes represented. The crown canopy is generally uneven in outline. Large stands often contain bare areas with irregular borders. Tree crowns and vegetation in general are vigorous in appearance.

9.9.3 Damage Criteria - Height of burst/damage distance curves for severe and light damage by air blast are presented in Figures 1, 2 and 3. The tree stand types referred to are those given above. Severe and light damage are defined in terms of length of stems down per acre, approximately 1500 ft. per acre for light damage and 9,000 ft. per acre for severe damage. These criteria are shown in terms of percentage of trees broken in Table I. The approximate number of trees per acre that may be expected for the three types of forest stand is also shown.

TABLE I - Percentage of Trees Broken for Light and Severe Damage to Forest Stands

Stand type	Trees per Acre	Light damage percent of trees broken	Severe damage percent of trees broken
I	75	15	90
II	260	10	60
III	200	10	60

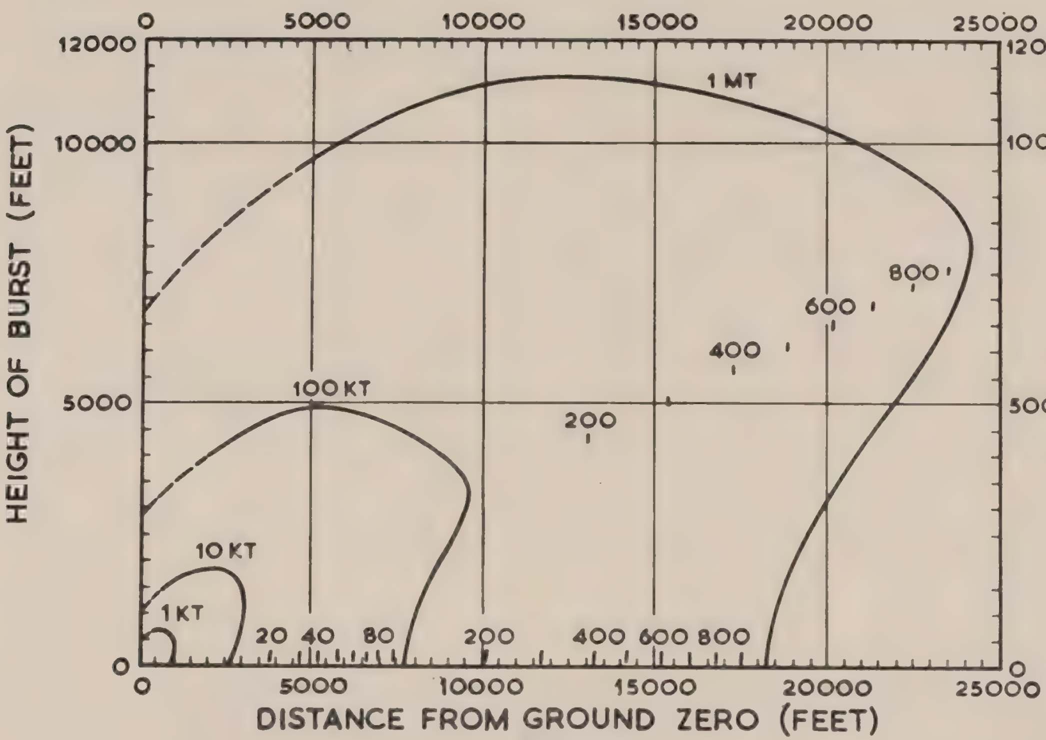


FIG. A

SCALE 1 MT CURVE WITH $W^{\frac{1}{3}}$ FOR LARGER YIELDS.
FOR DAMAGE DEFINITIONS SEE TEXT.
RELIABILTY – GOOD.

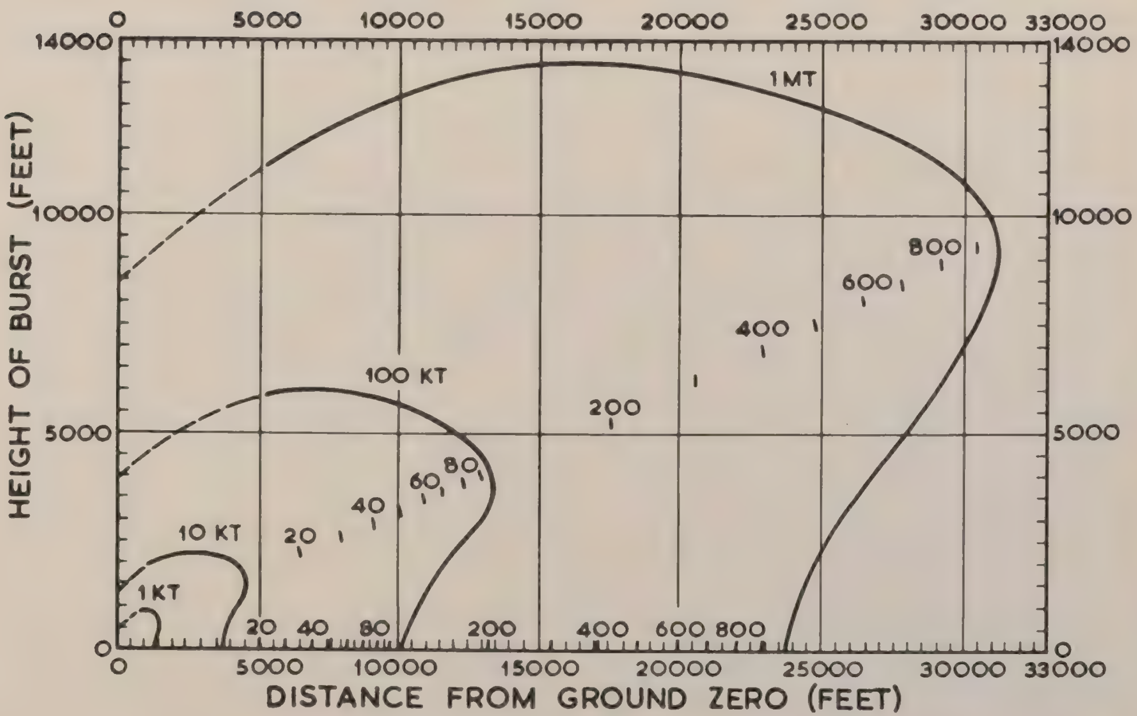


FIG. B

FIG. A. SEVERE DAMAGE TO TYPE I FORESTS
FIG. B. LIGHT DAMAGE TO TYPE I FORESTS

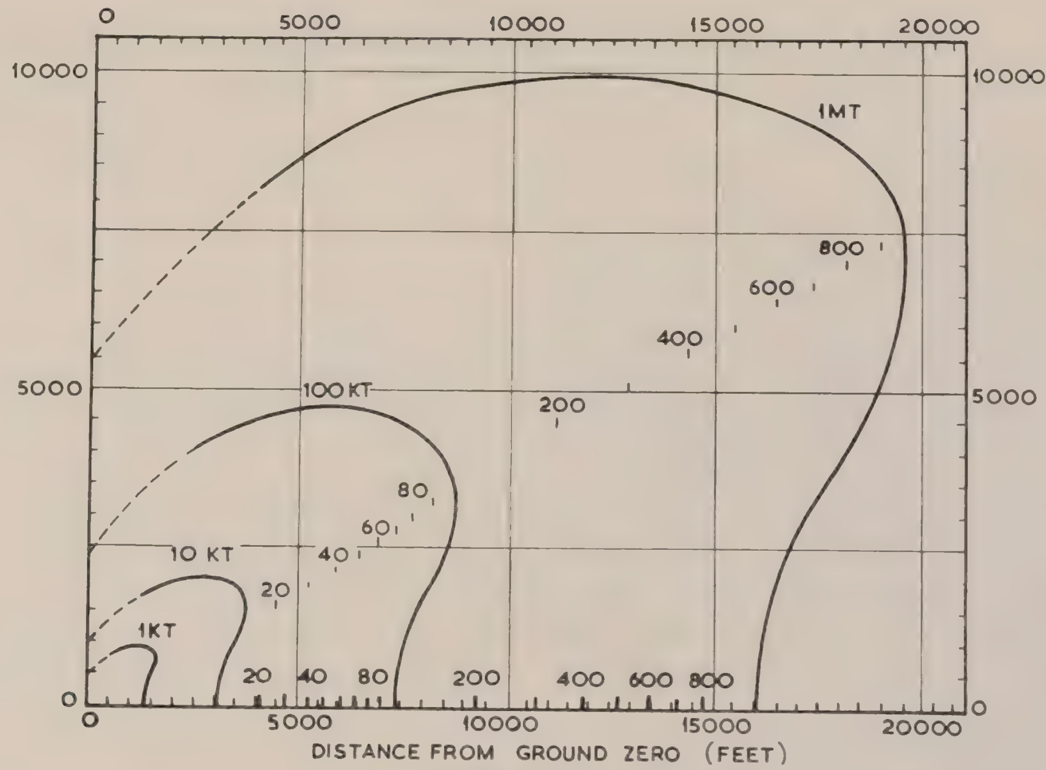


FIG. A

SCALE 1MT CURVE WITH $W^{1/3}$ FOR LARGER YIELDS. FOR DAMAGE DEFINITIONS SEE TEXT. RELIABILITY – GOOD.

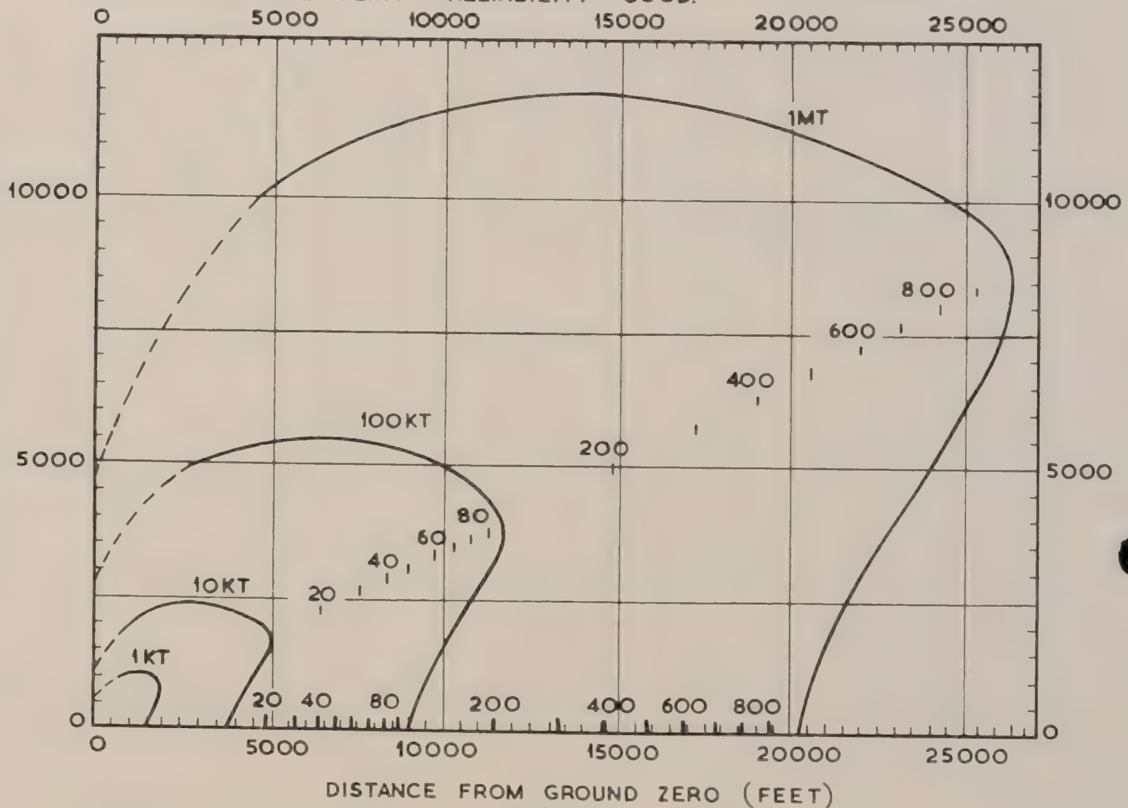


FIG-B

FIG. A. SEVERE DAMAGE TO TYPE II FORESTS
FIG. B. LIGHT DAMAGE TO TYPE II FORESTS

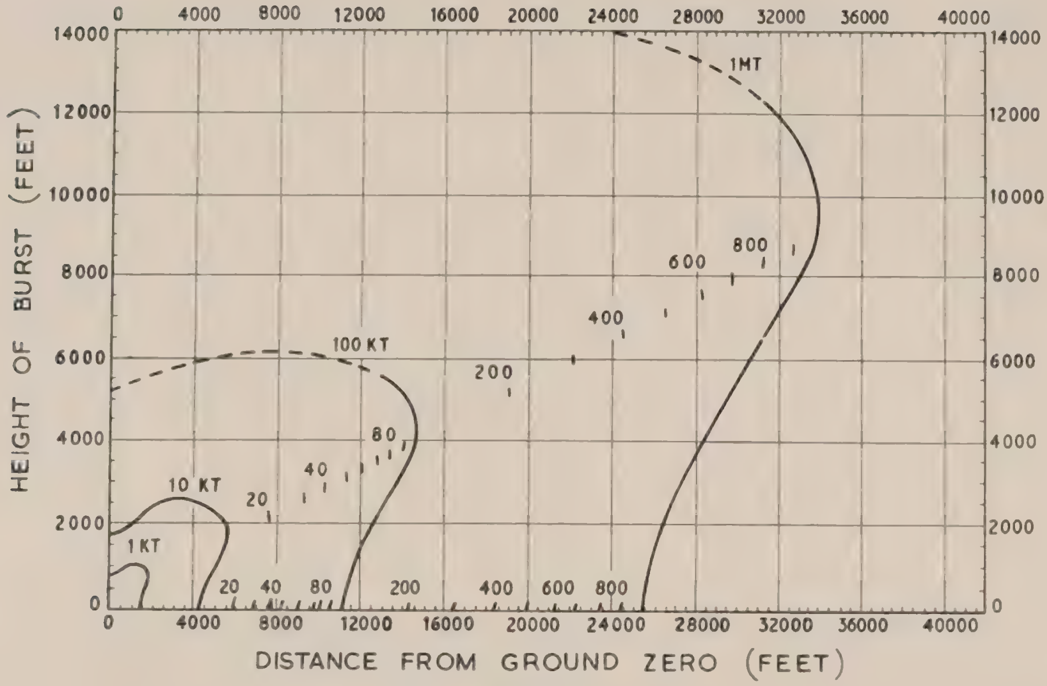


FIG. A

SCALE 1 MT CURVE WITH $W^{\frac{1}{3}}$ FOR LARGER YIELDS. FOR DAMAGE DEFINITIONS SEE TEXT. RELIABILITY — GOOD

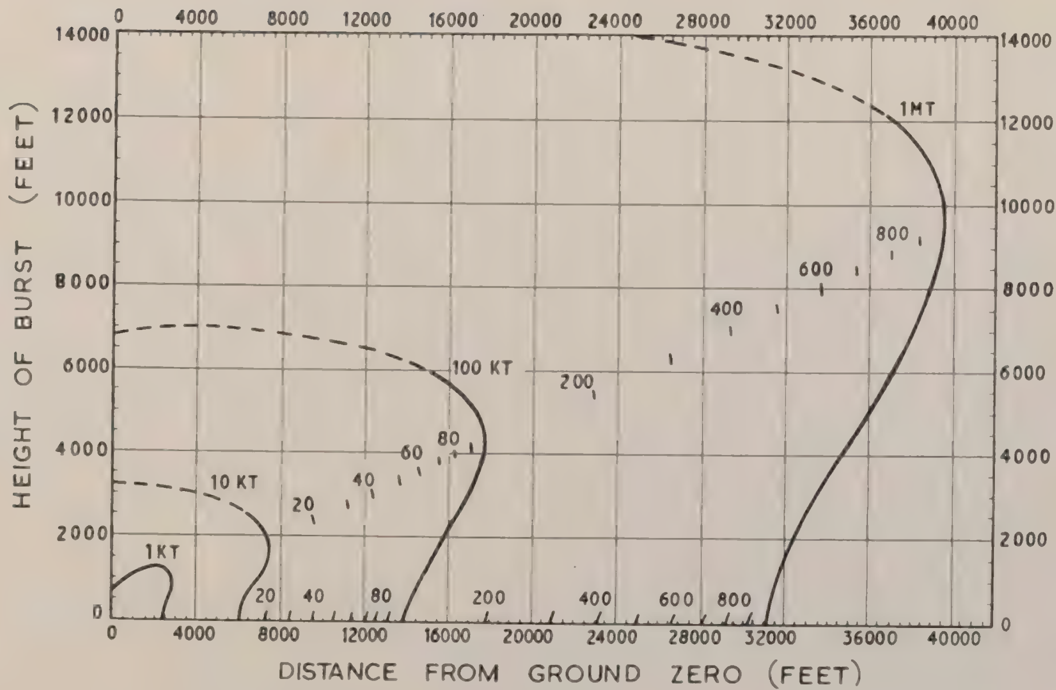
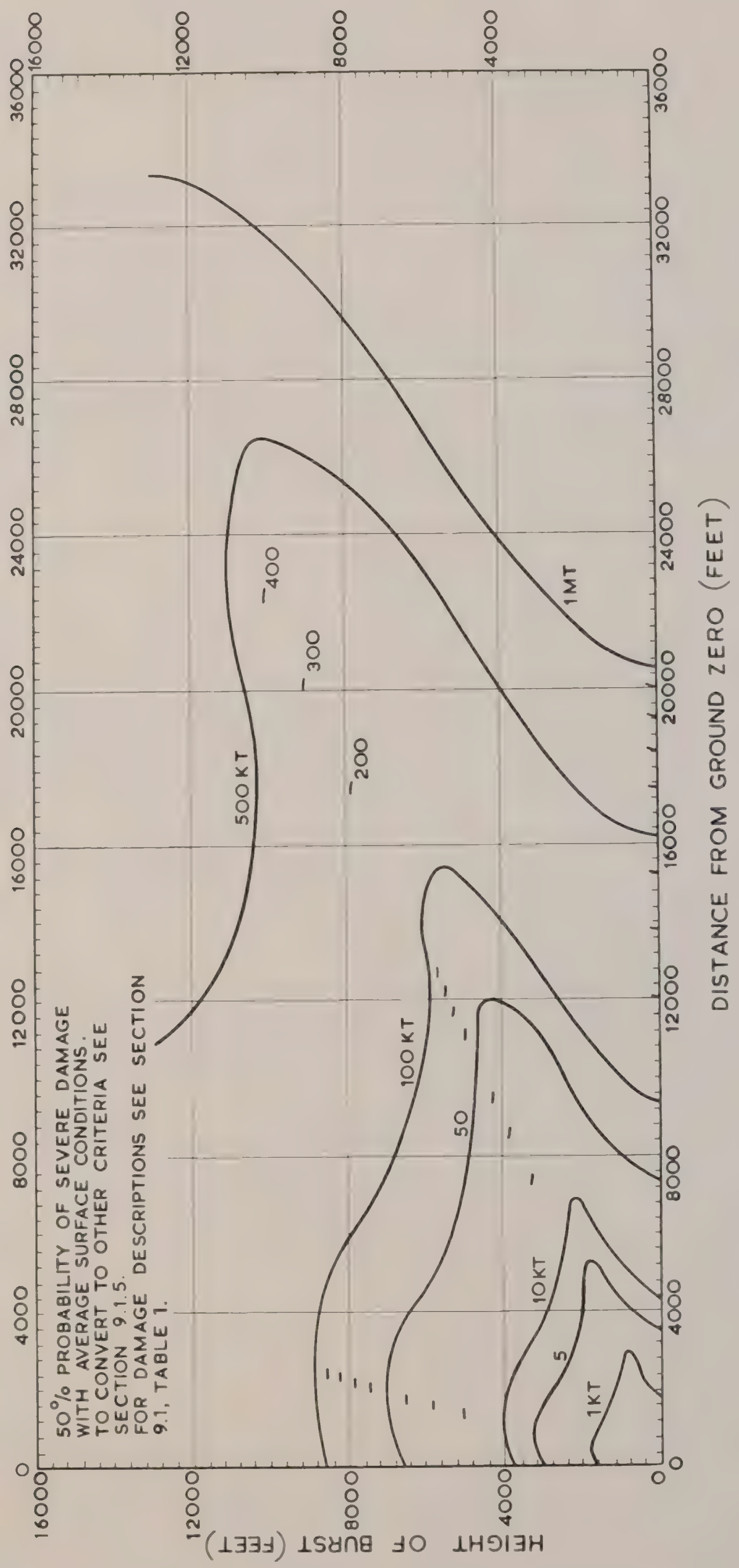


FIG. B

FIG. A. SEVERE DAMAGE TO TYPE III FORESTS
FIG. B. LIGHT DAMAGE TO TYPE III FORESTS



DAMAGE TO SINGLE AND 2-STOREY
WOODEN FRAME HOUSE

9.2.8. Bridges. Damage to bridges by bursts at low heights (up to $400W^{1/3}$ft.) is shown in Figure 1 for yields from 0.1 KT to 100 MT. The curves apply to highway and railway truss bridges for orientations of blast propagation from 45° to 90° from the longitudinal bridge axis. The given distances of Figures 2 and 3 are to be reduced to 60% for an orientation of 0° for all span lengths. In the case of orientations between 0° and 45° a linear interpolation is to be used.

The damage curves of Figure 4 apply to floating bridges types M-2 or M-4 at all orientations./ Typical examples of severe, moderate and light damage are given in Table I of Section 9.1.4. The adaptation of these curves to give other damage levels or probabilities of damage is described in Section 9.1.5. The allowances to be made in the case of airblast damage from underground bursts are given in Section 9.1.6.

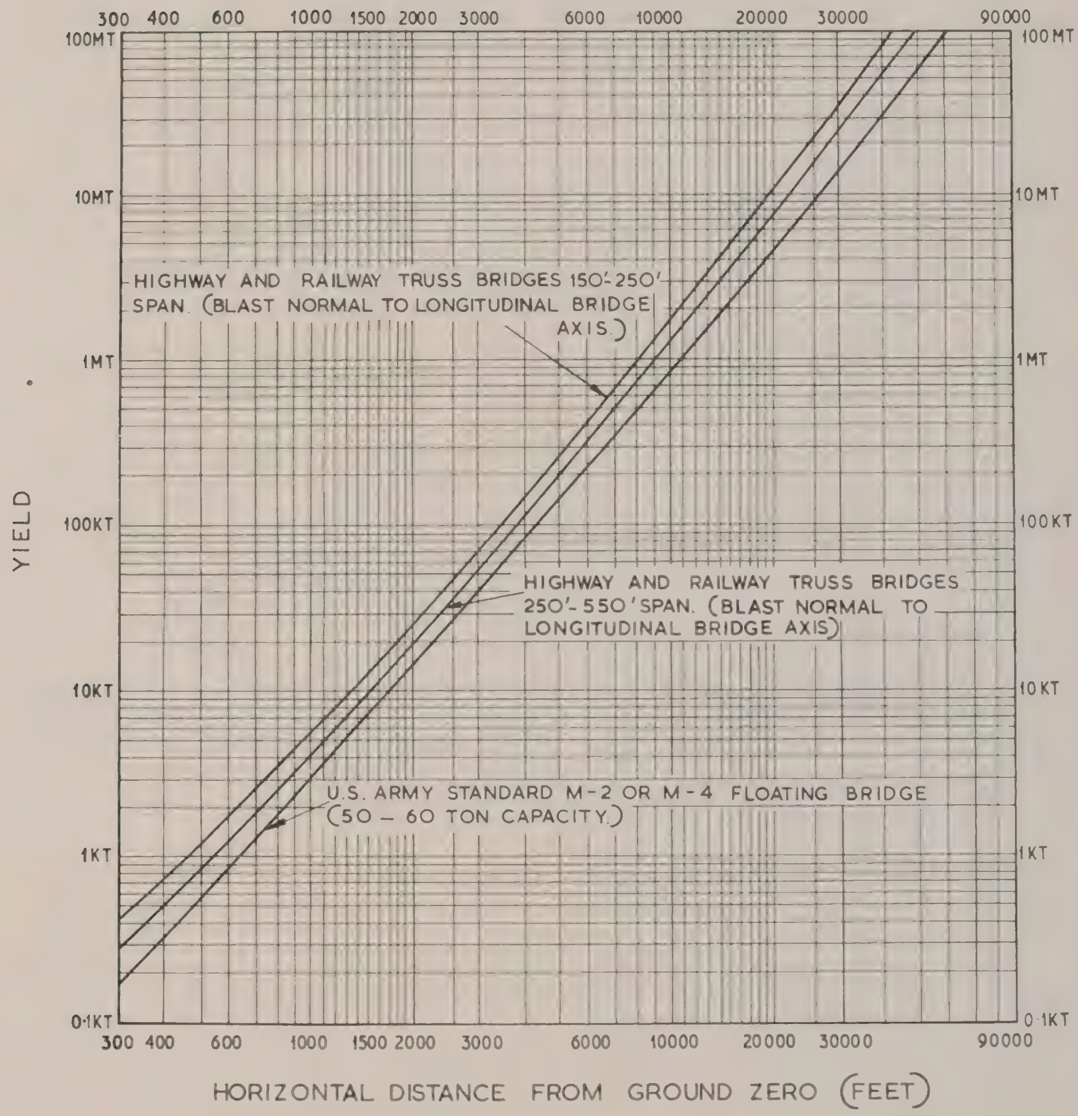
/ Note. Details of the U.S. Army standard floating bridges M-2 and M-4

M-2 - Capacity 44 tons safe, 50 tons risk, corresponds roughly to Class 40 safe and Class 50 for risk respectively. Two steel treadway tracks $45\frac{1}{2}$ in. wide with 63 in. gap. Rubber pneumatic floats of 24 tons total buoyancy at a centre spacing of 12 ft.

M-4 - Capacity roughly Class 50. Full width roadway of longitudinal aluminium baulks, carried on light alloy or steel open pontoons.

9.2.9. Oil Storage Tanks - The oil storage tanks for which damage curves are given in Figure 1 were 30 ft. high and 50 ft. in diameter. Empty tanks would be considerably more vulnerable and would probably suffer severe damage at ranges where only moderate or light damage would result when full. Typical examples of severe, moderate and light damage are given in Table I of Section 9.1.4. The adaptation of these curves to give other damage levels or probabilities of damage is described in Section 9.1.5. The allowances to be made in the case of airblast damage from underground bursts are given in Section 9.1.6.

BURST HEIGHT BETWEEN ZERO AND $400 W^{\frac{1}{3}}$ FEET. 50% PROBABILITY OF SEVERE DAMAGE. TO CONVERT TO OTHER CRITERIA SEE SECTION 9.1.5. FOR DAMAGE DESCRIPTIONS SEE SECTION 9.1. TABLE 1



DAMAGE TO BRIDGES BY BURSTS AT LOW HEIGHTS

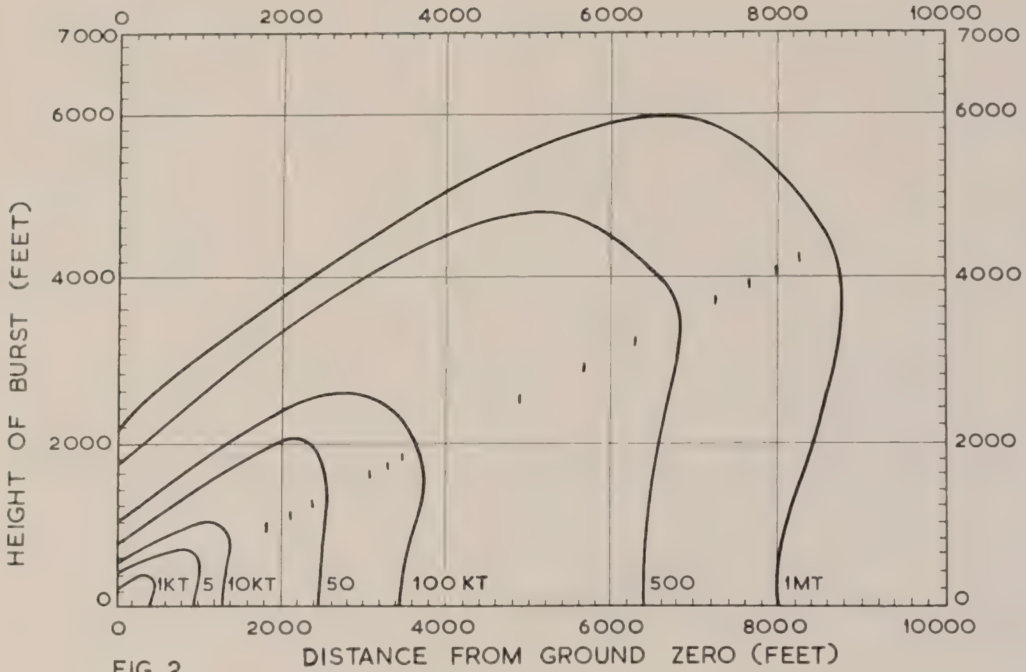


FIG. 2

50% PROBABILITY OF SEVERE DAMAGE. FOR 50% PROBABILITY OF LIGHT DAMAGE SCALE 0·6 P.S.I. DYNAMIC PRESSURE CONTOUR IN CHAPTER 1, SECTION 1.1. TO CONVERT TO OTHER CRITERIA SEE SECTION 9.1.5. FOR DAMAGE DESCRIPTIONS SEE SECTION 9.1. TABLE 1. BLAST STRIKING BETWEEN 45° AND 90° TO LONGITUDINAL AXIS OF BRIDGE. FOR ORIENTATIONS BETWEEN 0° AND 45°, INTERPOLATE LINEARLEY BETWEEN 60% AND 100% OF THE DAMAGE RANGES SHOWN

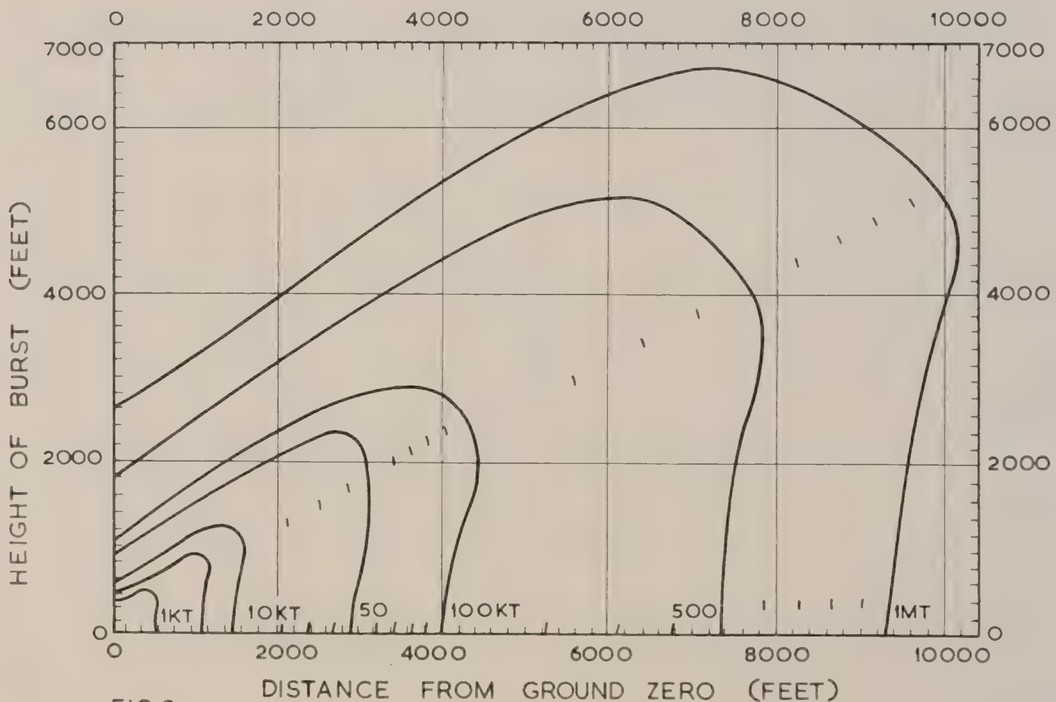
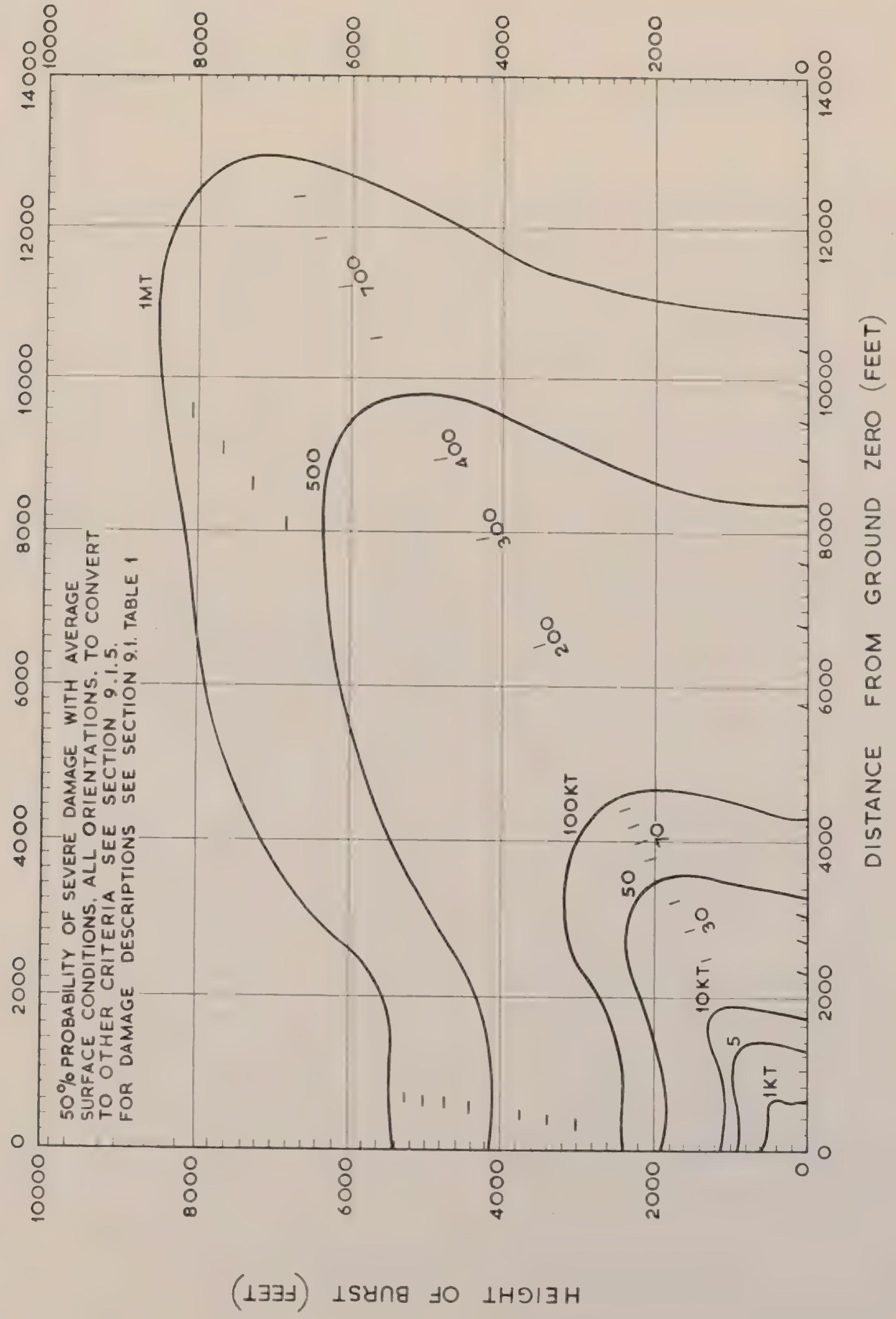
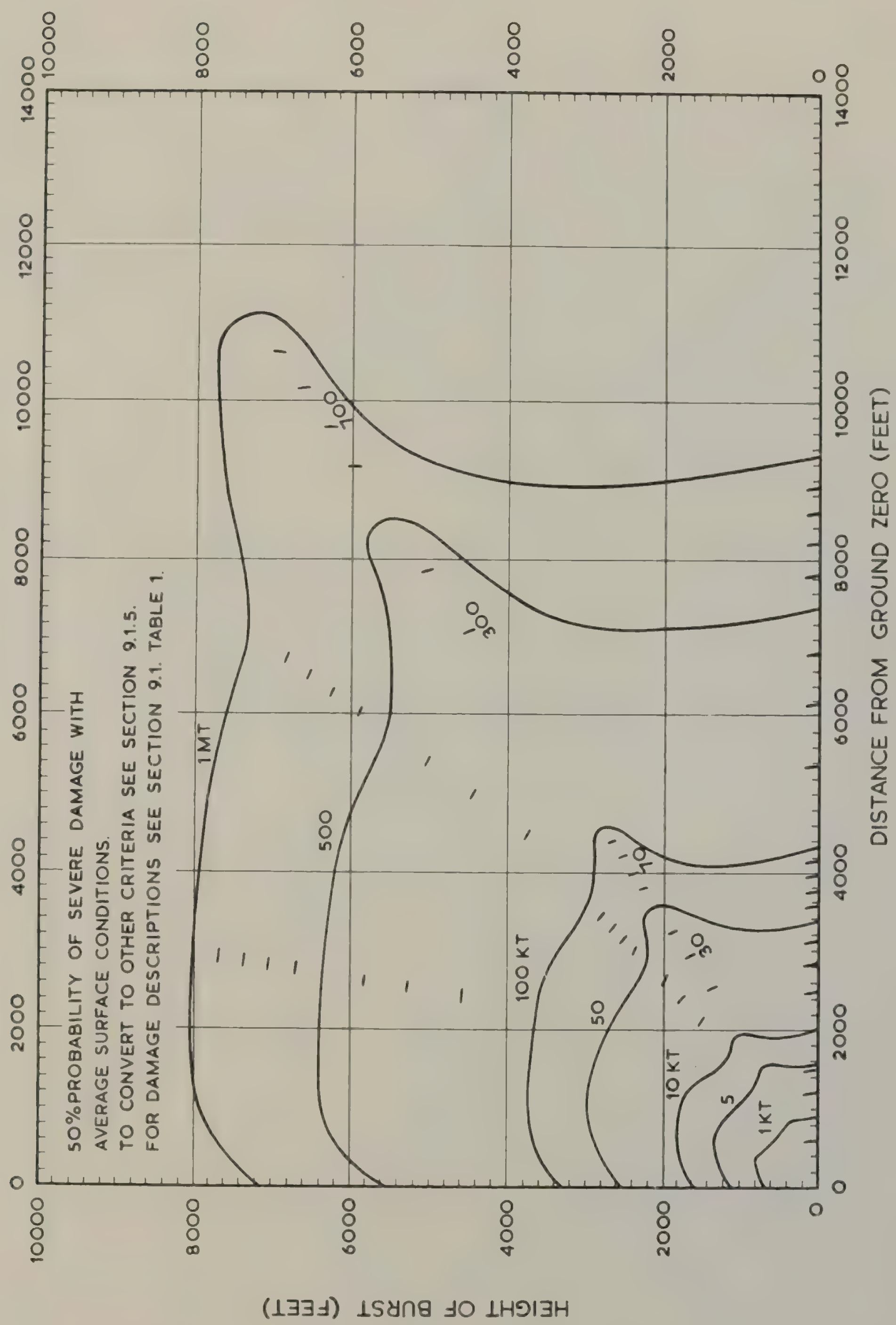


FIG. 3

FIG. 2 DAMAGE TO TRUSS BRIDGES OF 150′-250′ SPAN.
FIG. 3 DAMAGE TO TRUSS BRIDGES OF 250′-550′ SPAN.



DAMAGE TO FLOATING BRIDGES
TYPES M-2 OR M-4



DAMAGE TO FILLED OIL STORAGE TANKS

The influence of soil type

The influence of soil type on the various crater and ground shock parameters is discussed in detail in References (1), (2), (3) and (4). The variations of crater radius and depth with soil type are given in Table 1, in the form of approximate multiplying factors to be applied to "dry soil" data.

Table 1 - Influence of Soil Type on Crater Dimensions

Soil Type	Example	Factor for Crater Radii	Factor for Crater Depths
Hard rock	Maralinga +	0.8	0.8
Dry soil or soft rock	Nevada	1.0	1.0
Moist or damp soil	Pacific, on reef	1.5	1.5
Saturated soil	Pacific, on sand	2.0	0.7

The above factors are used to scale the dimensions of the crater and surrounding lip, rupturing and plastic zones. The symbols used for these parameters in this Manual are shown in Figure 3.

+ For further details of Maralinga site, see Chapter 2, Section 2.2, Table 2.

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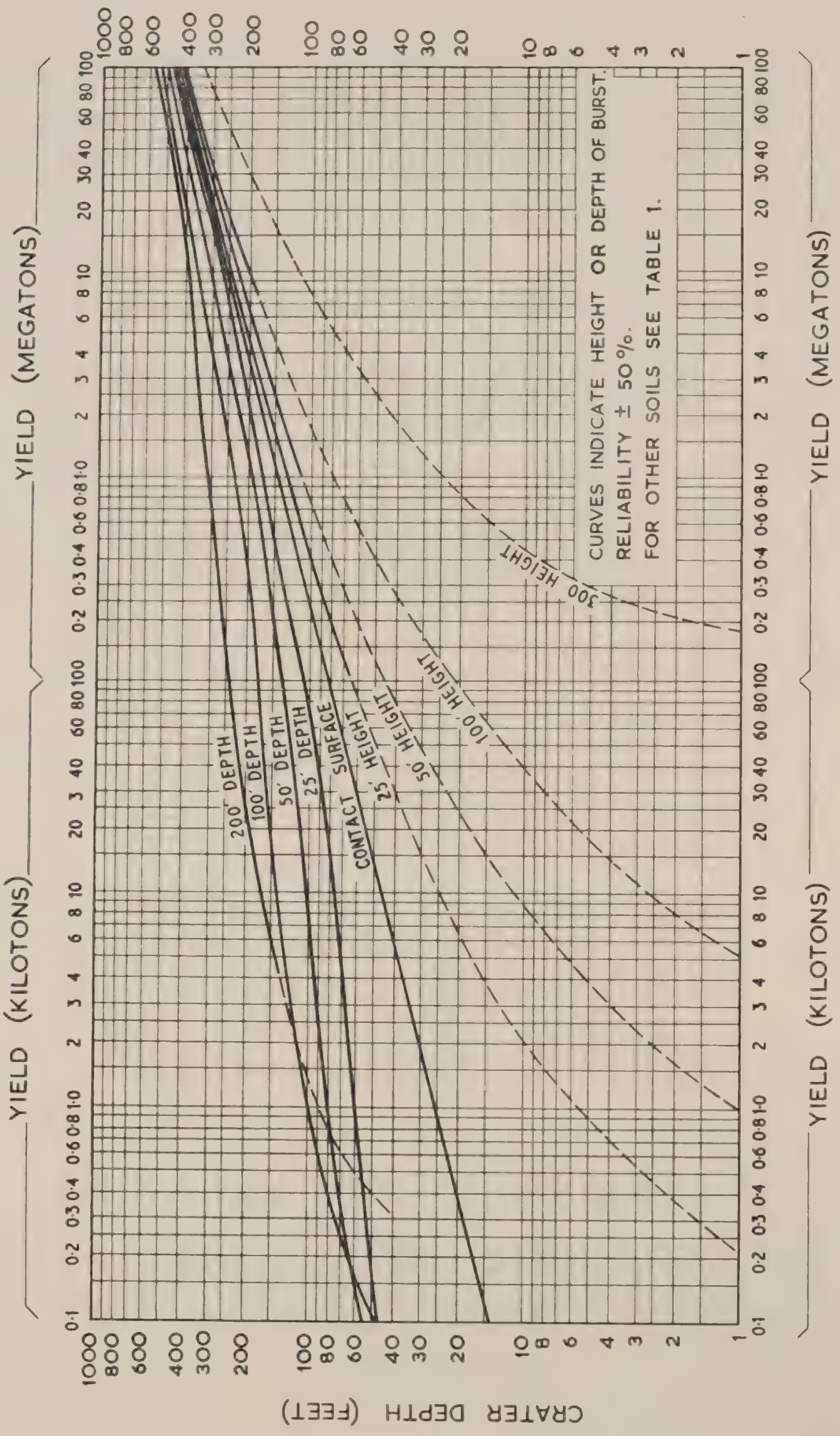

CRATER DEPTH IN DRY SOIL OR SOFT ROCK

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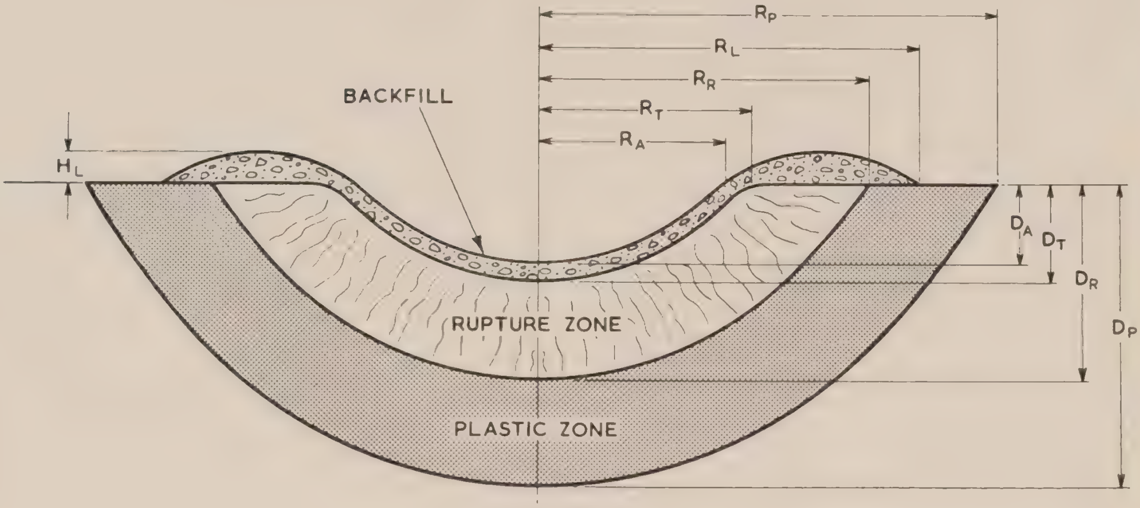
NOTE:–

CRATER RADII ARE MEASURED AT THE ORIGINAL GROUND LEVEL.

CRATER DEPTHS AND LIP HEIGHTS ARE MEASURED RELATIVE TO THE ORIGINAL GROUND LEVEL.

UNCERTAINTIES OF TERRAIN TEND TO MASK THE DISTINCTION BETWEEN TRUE AND APPARENT DIMENSIONS. WHEN NO DISTINCTION IS FEASIBLE, R_C AND D_C ARE USED FOR CRATER RADIUS AND DEPTH RESPECTIVELY.



R_A = APPARENT RADIUS OF CRATER, INCLUDING BACKFILL.

R_T = TRUE RADIUS OF CRATER WITHOUT BACKFILL.

R_R = RADIUS OF RUPTURE ZONE, APPROXIMATELY $1 \cdot 5\ R_A \pm 25\%$

R_L = RADIUS OF OUTER LIP OF CRATER, APPROXIMATELY $2\ R_A \pm 25\%$

R_P = RADIUS OF PLASTIC ZONE, SOMEWHAT GREATER THAN R_L FOR MOST SOILS BUT PRACTICALLY NON-EXISTENT FOR ROCKS.

H_L = HEIGHT OF LIP OF CRATER, APPROXIMATELY $0 \cdot 25\ D_A \pm 50\%$

D_A = APPARENT DEPTH OF CRATER, INCLUDING BACKFILL.

D_T = TRUE DEPTH OF CRATER WITHOUT BACKFILL.

D_R = DEPTH OF RUPTURE ZONE.

D_P = DEPTH OF PLASTIC ZONE.

V_A = APPARENT VOLUME OF CRATER (ASSUMED PARABOLOIDAL)
$= \pi\ R_A^2 .\ D_A / 2.$

V_T = TRUE VOLUME OF CRATER (ASSUMED PARABOLOIDAL)
$= \pi\ R_T^2 .\ D_T / 2.$

V_R = VOLUME OF RUPTURE ZONE.

V_P = VOLUME OF PLASTIC ZONE.

CRATER PARAMETERS

1.3. Scaling Laws

In this chapter use is made of the Scaling Laws already described in Part 1, Section 6, whereby corresponding parameters of two explosions may be related in terms of the ratio of their yields. Thus, if subscript o denotes the values as for a reference explosion of total power W_o kilotons the values for another explosion of total power W kilotons are found as follows:-

Energies	scale as (W/W_o)
Distance and Times	scale as $(W/W_o)^{\frac{1}{3}}$
Accelerations	scale as $(W/W_o)^{-\frac{1}{3}}$
Velocities and Densities	are invariant.

Note that phenomena which are critically dependent upon gravity do not scale according to these rules, since it is impossible to change gravity with weapon yield. Thus, effects such as those due to the hydrostatic pressure at appreciable depths in the ground give rise to important limitations in the application of experimental data. In practice crater radii are taken as scaling with $W^{\frac{1}{3}}$, and crater depths as scaling with $W^{\frac{1}{4}}$, to a sufficient degree of approximation.

2.2 Free Earth Pressures

Note.- For list of symbols see Preliminary, Page 2, of this Part.

In this section the pressures set up in the ground remote from any structure are described. The most detailed series of measurements of earth pressures was carried out in America by Lampson - Reference (1). Applying his results, which were obtained using H.E. charges, to atomic weapons, we may write the pressure (p) at distance R for depths greater than about 200 $W^{\frac{1}{3}}$ feet, as:-

$$p = FkWR^{-3} \qquad 2.2.1$$

This pressure is of the nature of an added hydrostatic pressure. The variation of the coupling factor (F) with scaled weapon depth is shown in Figure 1. This curve is only approximate, since it has been necessary to incorporate very uncertain data on explosive equivalence as a function of depth. The soil constant (k) varies widely from soil to soil and depends on the state of any given soil (e.g. moisture content) at the time of the explosion. The value of the constant was found to be correlated with the velocity of compressional waves in the ground, the so-called seismic velocity, by the relation:-

$$k = 2.5\rho v_T^2 \qquad 2.2.2$$

A list of soil constants is given in Table I for some typical soils.

TABLE I - Typical Soil Constants

Soil Type	Pressure Constant, k	Impulse Constant, B
Loess	2.2×10^8	4×10^6
Loam	5.6×10^8	12×10^6
Silty Clay	1.4×10^9	14×10^6
Clay-unsaturated	4×10^9	16×10^6
Clay-saturated	2.8×10^{10}	16×10^6

The pressure wave consists essentially of a single pulse, the shape and duration of which vary with distance from the weapon. The parameter which takes into account the pressure, duration, and shape of the pulse, is the impulse, which is defined as:-

$$I = \int_0^{\tau} p.dt$$

Lampson's results applied to nuclear explosions may be written in the form:

$$I = FBW^{7/6}\,R^{-5/2} \qquad 2.2.3$$

Values of the impulse constant (B) are given in Table I above for typical soils. B can be related to the seismic velocity (v_L), within an accuracy of 35% by the expression:-

$$B = 50\rho v_L \qquad 2.2.4$$

For generalised data on peak particle displacement, velocity, and acceleration as functions of distance from surface bursts, see M.E.A.W., Chapter 2, Data Sheet 2.4. Some full-scale British measurements at Maralinga are reported in Reference (4).

As the terrain at Maralinga is somewhat unusual, details of its physical characteristics have been derived from Reference (4), and are given in Table II.

Table II

P Physical Characteristics of the Rocks in the Geological Section at Maralinga

Depth of Layer	Type of Rock	Density gm/cc	Velocity (ft/sec.) P Waves (longitudinal)	Velocity (ft/sec.) S Waves (transverse)	Characteristic Impedance for P Waves c.g.s. units	Young's Modulus c.g.s. units
0/15 feet	Travertine limestone	2.7	5500 to 8500	-	5.8×10^5	1.2×10^{11}
thence to 75-80 feet	Sand underlying Travertine	2.0	2200 to 2700	-	1.5×10^5	0.3×10^{10}
thence to 200 feet	Sand and Clay	2.2	4300	-	2.9×10^5	2.7×10^{10}
thence to 1800 feet	Sandstone and/or Shales	2.5	11000 to 12000	8300 to 8600	8.8×10^5	3.1×10^{11}
tens of miles	Granite or Metamorphic Basement or limestone	2.7	19000	-	15.8×10^5	7.7×10^{11}

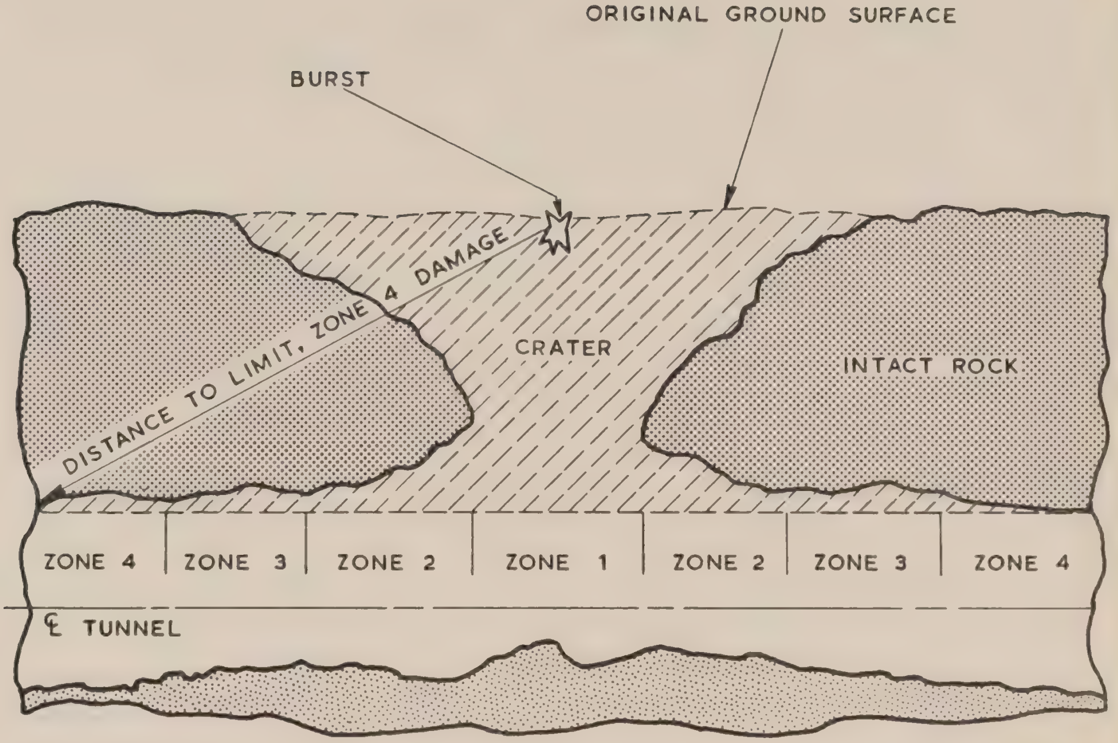
References

(1) Final Report on Effects of Underground Explosions, C.W. Lampson. N.D.R.C. Report No. A-479. O.S.R.D. Report No. 6645, March, 1946.

(2) Effects of Atomic Weapons. U.S. Government Printing Office, 1950. pp. 413-423

(3) Manual on The Effects of Atomic Weapons (Chapter 2). A.W.R.E. (Secret/Atomic/U.K. Eyes Only)

(4) Operation 'Buffalo'. Measurements of Ground Shock and Crater. A.W.R.E. Report T37/57. (Secret/Atomic)



ZONES OF DAMAGE TO UNLINED TUNNELS IN SOUND ROCK:—

ZONE 1. CRATER OPENING INTO TUNNEL.

ZONE 2. INCREASING THICKNESS OF SPALLING.

ZONE 3. CONTINUOUS SPALLING OF ABOUT CONSTANT THICKNESS.

ZONE 4. INTERMITTENT LIGHT SPALLING.

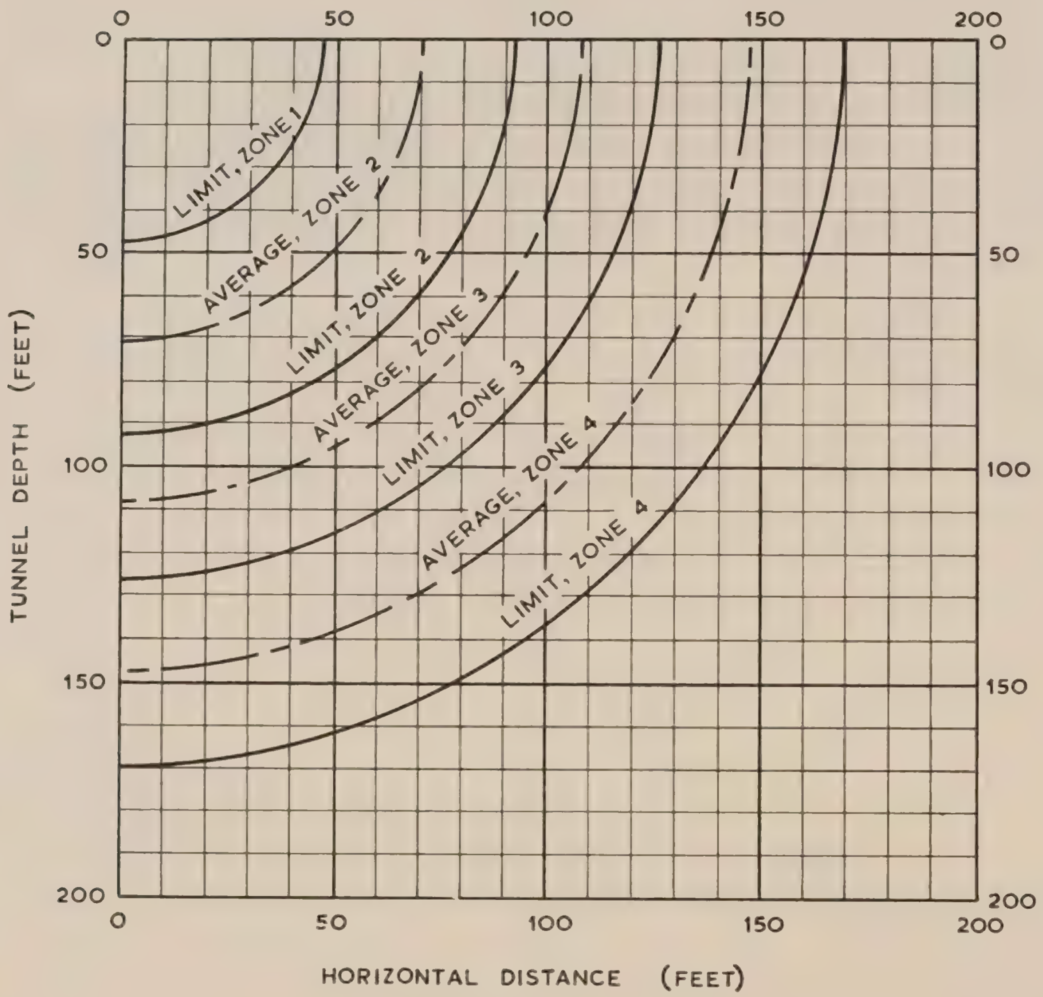
DAMAGE ZONES FOR TUNNELS

CURVES REPRESENT 1 KT CONTACT SURFACE BURST.

TO OBTAIN DAMAGE DISTANCES FOR OTHER YIELDS, MULTIPLY TUNNEL DEPTH AND HORIZONTAL DISTANCE BY $W^{\frac{1}{3}}$.

FOR OTHER SOILS SEE TABLE 1.

FOR UNDERGROUND BURSTS SEE TEXT.



APPROXIMATE ISODAMAGE CONTOURS
FOR UNLINED TUNNELS IN ROCK

Table 1 (Contd.)

Intensity	Acceleration	Effects
X	0.6g	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	1.4g	Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe pines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	3g	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 2

	Energy Range ergs	Magnitude of mean
Great earthquakes	10^{26}	8.
Major earthquakes	$10^{24} - 10^{26}$	7.5
Destructive earthquakes	$10^{22} - 10^{24}$	6.5
Damaging earthquakes	$10^{20} - 10^{22}$	5.5
Minor strong earthquakes	$10^{18} - 10^{20}$	4.5
Generally felt small earthquakes	$10^{16} - 10^{18}$	3.0

For further discussion see Reference (3)

The earthquake damage scale given in Table 3 was used by the National Research Council in Reference (4). The accelerations given in the Table are those in a horizontal direction.

Table 3 - Earthquake Damage Scale

Grade A - Very violent (greater than 0.4 gravity).

Grade B - Violent (0.3-0.12 gravity).
Fissuring of asphalt; destruction of foundation walls and under-pinnings of structures; the breaking of sewers and water mains; displacement of street car tracks.

Grade C - Very strong (0.12-0.08 gravity)
Brick walls or masonry badly cracked with occasional collapse; frame buildings lurched or listed on fair or weak underpinning; general destruction of chimneys and masonry, cement or brick veneers; considerable cracking or crushing of foundation walls.

Table I

Item	Damage	Velocity (ft./sec.)	Remarks
Bridges	Severe	1.6	Bridge collapses
	Moderate	0.85	Bridge displaced
Airfield Runway Landing mat (steel)	Severe	1.1	Mat twisted and buckled
Airfield Runway* Landing strip (concrete)	Severe	2.0	Concrete cracked and displaced
	Moderate	1.5	Concrete will crack
	Light	1.0	Concrete slightly cracked
General Machinery (bolted down)	Severe	0.8	Gears and functional parts destroyed
	Moderate	0.6	Auxiliary equipment destroyed
	Light	0.5	Destroys alignment
Railway locomotives and rolling stock	Severe	1.1	Pushed over and twisted Probable fires
	Moderate	0.7	Derailment
Brick walls (12-18in.)	Severe	0.6	Collapse
	Moderate	0.5	Partial collapse and cracking
	Light	0.4	Cracking
Houses - brick	Severe	0.6	Collapse
	Moderate	0.5	Distortion and cracks
	Light	0.4	Plaster and window damage
Houses - wooden frame	Severe	0.8	Collapse
	Moderate	0.6	Distortion and cracks
	Light	0.45	Plaster and window damage
Multistory brick building	Severe	0.6	Collapse
	Moderate	0.5	Structural damage
	Light	0.4	Plaster and window damage
Reinforced concrete building	Severe	0.85	Collapse
	Moderate	0.7	Structural damage
	Light	0.6	Plaster and window damage
Steel, heavy frame building	Severe	0.7	Mass distortion
	Moderate	0.5	Structural damage
	Light	0.45	Plaster and window damage
Steel, light frame building	Severe	0.6	Mass distortion
	Moderate	0.5	Structural damage
	Light	0.4	Plaster and window damage
Underground pipes*	Severe	0.85	Pipes broken
Dams (cement)*	Severe	1.0	Cracked and displaced
Dams (earth)*	Severe	1.6	Cracked and displaced
Submarine pens*	Severe	1.6	Cracked and displaced
Railway lines*	Severe	1.6	Rails bent

*Note: There is experimental evidence to support this figure with these items.

4.5. The Resistance of Structures

As stated in Section 4.4, the inertial forces acting on a structure and its internal resistance, both depend in a complex manner on the motion of its base and on the previous plastic deformations which the structure may have undergone. However, it is possible to define approximately the resistance of a structure by the equivalent damping and restoring force method. The behaviour of the structure is then defined by the constants n and ω_o of equation 4.4.2.

The damping constant n varies widely from building to building, measured values having been found between n=0.001 and n = 0.5. For a structure vibrated well into its plastic region, the value of n is expected to lie between 0.1 and 0.5.

An extensive survey of the fundamental frequencies of buildings has been undertaken by the United States Coast and Geodetic Survey - Reference (1). They find that although factors such as the shape of the building, type of construction, and the type of ground on which the structure is built, all affect the fundamental period, it is possible to define ω_o to a fair degree of approximation by the equation:

$$\omega_o = 120\sqrt{b/h} \qquad 4.5.1.$$

where ω_o = 2π times the fundamental frequency (sec $^{-1}$)

b = the breadth of the building (feet)

h = the height of the building (feet)

When these values of n and ω_o are fitted into equation 4.4.2. that equation suffices to define the motion of a building at any time. If the amplitude of the induced vibration exceeds a certain value, the structure will collapse. Little information is available on this critical value. In a single experiment a brick farmhouse was demolished by A.W.R.E. - Reference (2) - and it was found that the structure collapsed under a steady pull when the centre of gravity had been displaced laterally through a distance of about 10 percent of the height of the building.

It should be emphasized that this is an isolated example, and that the house was demolished by a single slow pull rather than by transient oscillatory forces.

References

(1) F. P. Ulrich and D. S. Carder - "Vibrations of Structures" Symposium on Earthquake and Blast Effects on Structures". Los Angeles, June, 1952.

(2) Static Demolition of a Farmhouse. A.W.R.E. Report H3/51 (Restricted)

CHAPTER 6

The Vulnerability of Underground Installations and other Protective Construction to the Effects of Nuclear Weapons

Editor's Note

This chapter was originally prepared as a paper for the Nuclear Weapons Lethality Committee, and at the Committee's request is now published as a chapter of the manual.

A list of reports relating to the vulnerability of protective construction has been compiled and is presented at the end of the chapter. Many of these reports are of U.S. origin and some are not yet available in the U.K. A comprehensive review of this information has therefore not been possible. However, with the possible exception of earth shock, the response of protective installations to nuclear effects is sufficiently predictable to permit their design and construction to specific levels of protection with reasonable confidence.

It was with this object that the U.S. publication "Protective Construction Review Guide" was written in late 1958, and it represents the U.S. philosophy on the subject at that date. This paper is substantially a summary of the "Review Guide", with the object of highlighting the structural requirements, design features, and approximate costs of protective installations, particularly underground construction required to withstand severe stresses.

The Vulnerability of Underground Installations and other Protective Construction to the Effects of Nuclear Weapons

1. Introduction

In designing an installation to resist nuclear weapons the following weapon effects must be considered:-

(i) the immediate nuclear and thermal radiation:

(ii) the shock transmitted through the ground:

(iii) the blast forces:

(iv) the radiation from fallout, and induced radiation resulting from the immediate effects of neutrons on materials.

The level of radiation intensity and of shock and blast which an installation must resist depends on a number of factors over which the designer has no control. These include: the size of the weapon and the distance from the target at which it is detonated, or the overpressure level which is produced at the installation by the weapon considered; the number of weapons which are successfully detonated in the vicinity of the installation; and the overall pattern of attack, which may bring residual radiation from fallout to a target which is not near any nuclear burst. To deal with these factors the designer may select the ground environment, the structural mass and strength of the elements of the installation, and the arrangement and multiplicity or duplication of those elements in a pattern which will give the desired probability of survival.

This leads to tentative conclusions on design parameters which may have to be modified in the light of operational conditions, and survival criteria for personnel and materials. A selection must then be finally made of the structural type and design parameters, which can be stated generally in terms of the overpressure level and radiation intensity levels, for both immediate and residual radiation, and the level of earth shock, for which each element of the facility must be designed.

2. Structural Design

As mentioned above, in order to obtain design parameters for a structure, conditions must be chosen which the structure must resist to give the desired probability of survival. For example, given the yield and C.E.P. of the weapon against which protection is being designed, and having chosen an appropriate probability of survival consistent with the importance of the facility, a radius of vulnerability (Rv) may be obtained from Figure 1. Then from Figure 2 using this Rv and the chosen yield, a value of the maximum overpressure for the selected survival probability may be found. In a similar manner Rv may be related to initial radiation dose. The necessary charts for this are not given here but are available in References 25 and 26.

It is then necessary to determine the structural resistance required, taking into account the span or other controlling dimensions of the structure, the structural materials, and the range of behaviour of the structure for which the design is being prepared.

Appendix 5A of Reference 1, give a series of design charts which may be used to determine the approximate size required for various structural elements such as slabs, beams, arches, domes, columns, footings or frames for any level of overpressure.

In order to determine the required size of elements it is necessary to use the dynamic strengths of the materials, for example the dynamic compressive strength of concrete and the dynamic yield strength of steel. The magnitude of these dynamic strengths, taking into account increase in strength due to the rapid rate of loading, may be found in Appendix 5B of Reference 1.

The requirements for nuclear radiation protection must also be assessed from knowledge of the initial radiation dose (unshielded) and the permissible exposure level inside the installation. For example approximately 100 inches of soil, or about 70 inches of concrete will reduce an initial gamma radiation level of 1,000,000 r to a level of 100 r (possibly an acceptable operational dose). For details of gamma-ray shielding References 25 and 26 should be consulted. Similar neutron attenuation data are not given in these two references, but Figure 3 provides some information on this subject.

Nuclear radiation effects on electronic equipment, and the effects of electro-magnetic flash must also be considered, and suitable protection provided. Some information on this subject is given in References 27, 28, 29 and 30.

Thermal radiation intensity is unlikely to be a predominant factor for structures already designed to withstand severe blast overpressure and provide adequate nuclear radiation shielding. The outside surface of the structure will however suffer severe thermal exposure. For example, at 7,000 ft. from 20 M.T. (equivalent to an overpressure of 200 p.s.i.) the thermal radiation dose is about 4,000 Cal/cm^2.

3. Structural Details

3.1. Concrete Construction. Reinforced concrete is an excellent material for blast-resistant construction, but strict attention must be paid to details in order to assure continuity, ductility and resistance to loads in either direction. In no case should the amount of reinforcing used on any face of a beam or slab exceed 2% of the cross-section area of the element, in order to avoid brittle behaviour.

3.2. Steel Construction. Steel also can be used very economically for certain types of blast-resistant construction. Arch or circular sections for underground construction, steel beams for composite construction, high strength columns, and steel doors for personnel or equipment entrances are elements which may be more economically constructed of steel than of reinforced concrete.

Ductility, continuity and development of full plastic strengths at joints are also recommended for steel construction. Steel members designed for maximum plastic resistance should be able to experience large deflections without reduction in load capacity. Generally such members will be stockier than in conventional design. Recommendations of proportions which would minimise or avoid buckling problems are given in Appendix 5B of Reference 1.

TABLE I

COST DATA FOR LIMITED COST ESTIMATES

Item	Costs (cy = cubic yard, S.F. = sq.ft., L.F. = lin. ft.)			
	Above Ground	Mounded or Shallow u/g (25' cover)	Deep Underground	Remarks
1. Excavation and Backfill	Dollars/cy	Dollars/cy	Dollars/cy	
Backfill	2	3	–	
Excav. Earth	3	3	6	
" Soft Rock	6	6	15	
" Hard Rock	10	10	25	
" Added cost if ground water problem	–	Add 50%	Add 100%	
2. Structural	Dollars/S.F.	Dollars/S.F.	Dollars/S.F.	
Walls, roof, floors and foundations, building frame and cladding, exclusive of interior partitions, finishes and excavation	9 (soft) See Figures 4, 7, 8, 9	See Figures 4, 7, 8, 9	Unlined 20 Lined 25	Structural costs vary with structural type, span, and design overpressure
3. Entrances, Doors	(See Figures 4, 5 and 10) Add 3 dollars/ S.F. of door for radiation shielding at 25 p.s.i.	(See Figures 4, 5, and 10) Add for stairs or ramps	(See Figures 4, 5 and 10) Multiply by factor 1.5; access tunnels under Item 7	
4. Architectural (Interior finishes, partitions, etc.)	4 – 9	4 – 9	10 – 22	Lower figures apply to simple interior layout, higher figures to multipartitional layout, acoustic treatment, etc.
5. Mechanical (Heating, ventilating, air conditioning, air filtration, plumbing)	Dollars/S.F. 4 – 7	Dollars/S.F. 4 – 7	Dollars/S.F. 5 – 8 But add to excav. and struct. costs	Includes 1.50 dollars/S.F. for decontam., air filt., blast valves, etc. Refrigeration costs for cooling electronic equipment, and ice storage for emergency used must be added
6. Electrical (Lightning, electrical outlets, normal power connections)	3 – 5	3 – 5 But add to excav. and struct. space	4 – 6 But add to excav. and struct. costs	Includes 1.0 dollars/S.F. for minimum admin. standby. For operational standby add 300 dollars/K.W. for generators and switchgear.
7. Water Supply; Sanitary; Ventilation shafts and tunnels; Personnel shafts and tunnels	250 dollars/ person for water; 350 dollars/person for sewerage; 20 D dollars/S.F. (for D = 10' dia.) 30 D dollars/L.F. (for D = 10' dia;)	Same as for above ground	350 dollars/person for water 450 dollars/person for sewerage	For shafts and tunnels, cost of excav. or tunnelling must be added.
8. Site Improvements Access Roads, Power transmission, Communications, etc.				

NOTE: All costs are referred to 1959 indices (U.S.) and Geographical Factor of 1.0.
Costs consist of contract costs plus about 20% for contingencies and inspection.

A. General Design Studies

Ref. No.	U.K. Reference	U.S. Reference	Author	Title	Security Classn.	Remarks
1.	Home Office CD 12237	OASD (P & I)	N.M. Newmark R.J. Hansen M.J. Holley J.M. Biggs	Protective Construction Review Guide - Unclassified Extracts issued for University of Illinois and M.I.T. Jan. 1959	U	Very useful general review, with bibliography.
2.	DGAW 764/60	ASTIA Document AD 150659 R and S-69	Rand Corp.	Proceedings of the Symposium on Protective Construction May 1957	Secret Atomic	
3.	TIL Numbers P.57300 and P.57301	U.S. Army Contract DA-49-129-eng-120	Amman and Whitney	Design of Structures to Resist Atomic Blast 2 vols.	C	A very detailed study
4.		Bull. Virginia Polytech. Inst. Eng. Ext. Station No. 106	N.M. Newmark	Analysis and Design of Structures to Resist Atomic Blast Jan. 1956	U	
5.	DGAW 387/60	Trans.Amer.Soc. Civ. Eng. 121 1956, pp.45-64	N.M. Newmark	An Engineering Approach to Blast Resistant Design	U	A simplified study of design essentials
6.	MEXE, A.D.292	BuDocks Instruction 3441.2, Sup -1	U.S.N. Bureau of Docks and Yards	Studies in Atomic Defence Engineering	U	
7.	MEXE, AD.295 Home Office CD 12336	Atomic Defence Eng.Tech. Study 28	W.J. Christensen (U.S.N. Bureau of Docks and Yards)	Relative Vulnerability of Underground Protective Construction Sept. 1959	U	
8.		Atomic Defence Eng. Tech. Study 27	W.J. Christensen	Air Blast Induced Ground Shock	U	
9.		Civil Eng.Studies Structural Research Series, No. 149	J.L. Merritt N.M. Newmark (University of Illinois)	Design of Underground Structures to Resist Nuclear Blast		
10.		Armour Research Foundation. Final Report on Proj. K.149	K.E. McKee R.W. Sauer	Evaluation of Deep Tunnel Shelters Nov. 1958	U	
11.		Draft Engr. Manual Military Construction EM 1110-345-421		Design of Structures to Resist the Effects of Atomic Weapons, Buried and Semi-Buried Structures		
12.	DGAW 283/60	Contract DA-49-129-eng-312	J.L. Merritt G.F. McDonough N.M. Newmark	Evaluation of Data from Underground Explosion Tests in Soil. Vol. I, Final Report, May, 1958	C Atomic	
13.	DGAW 622/60	"	J.L. Merritt N.M. Newmark	Vol. II, Design of Underground Structures to Resist Nuclear Blast	U	
14.		Armour Research Foundation, Final Report on Project K.138		Study of the Feasibility of Tunnel Closures to Resist Nuclear Blast Aug. 1958	U	
15.	MEXE, AD.297	Eng.Manual Mil. Constr. Part XXV		Chapters 1-6. Heating and Air Conditioning of Underground Installations (1956)		
16.	MEXE, A.D. 298-305	U.S. Army Corps of Engineers Manuals EM 1110-345-413, 414, 415, 416, 417, 419, 420, 461	M.I.T.	Series of U.S. Army Manuals dealing with the design of structures to resist the effects of atomic weapons	U	
17.	Home Office CD 12412		D.G. Christopherson	Theoretical Treatment of Blast Induced Earth shock	C	

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37		ITR-1404		Operation Plumbbob. Ground Acceleration, Stress, and Strain at High Incident Overpressures	C	
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42		ITR-1447		Operation Plumbbob. The Internal Environment of Underground Structures subjected to Nuclear Blast. I - The occurrence of dust	O.U.O.	
43	DGAW 67/59	ITR-1448		Operation Plumbbob. Field Test of Reinforced Concrete Dome Shelters and Prototype Door	O.U.O.	
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45		ITR-1459		Operation Plumbbob. Evaluation of Industrial Doors Subjected to Blast Loading	O.U.O.	
46		ITR-1460		Operation Plumbbob. Test and Evaluation of Anti-Blast Valves for Protecting Ventilation Systems	O.U.O.	
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53	DGAW 573/60	1960/R-5		Vol. II Comparative Evaluation		
54		1960/R-6		Vol. III Hardening		
55	DGAW 350/60	SADTC Paper for 5th SHAPE OR/SA Conference	J. L. Jenkins	Hardening and Other Passive Defense Techniques	NATO SECRET	Basically the same as SADTC Report 1960/R-4
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65	AWRE Report O-19/54		J. K. Wright J. D. Herbert	Considerations leading to a programme for the study of ground shock and the necessary instrumentation.	C	
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Ref. No.	U.K. Reference	U.S. Reference	Author	Title	Security Classn.	Remarks
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69	AWRE Report 0-25/56		J. K. Wright J. D. Herbert	Measurement of ground shock in homogeneous media. Part 1. The surface movement due to a 2 oz. charge detonated on the ground.	C	
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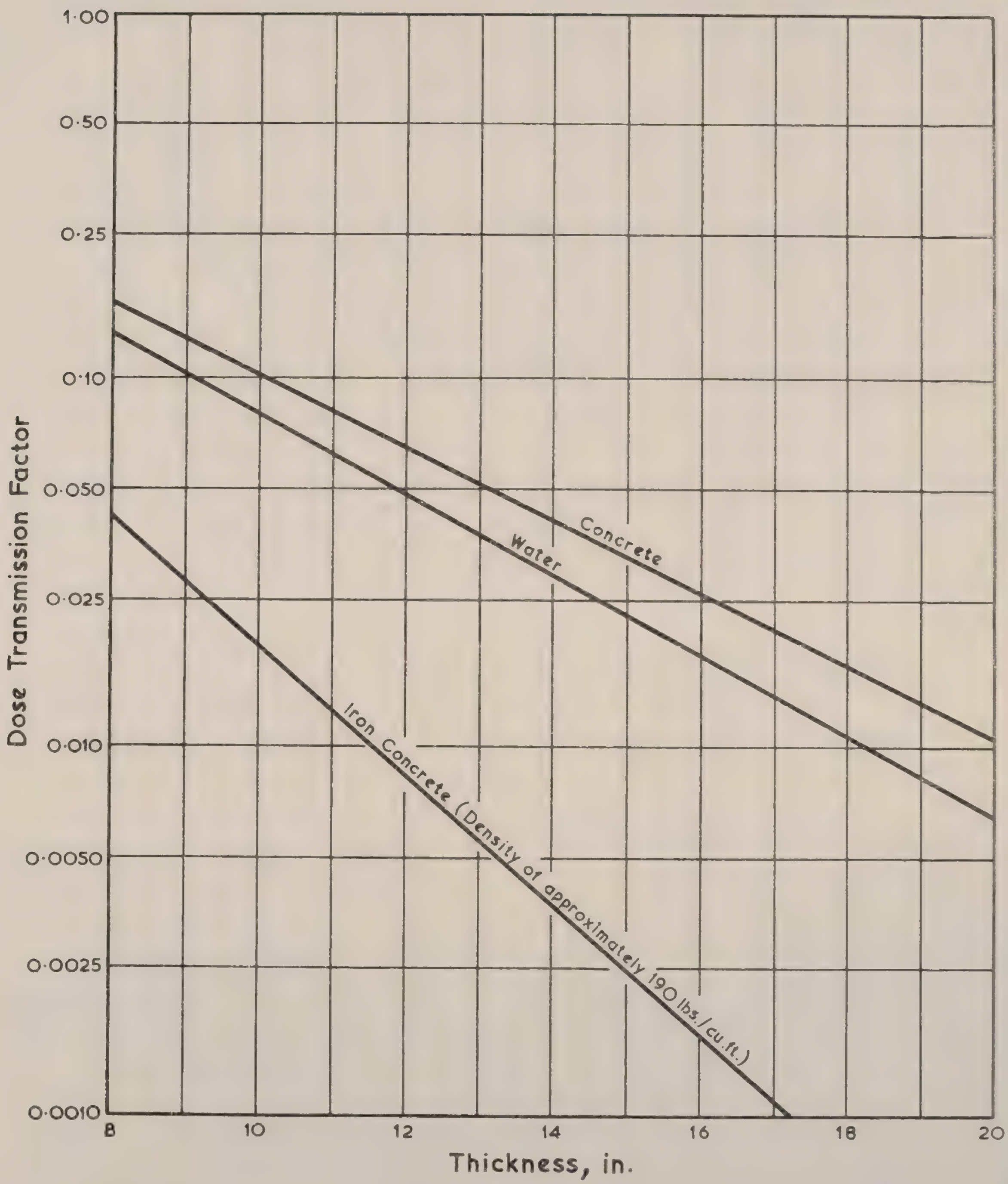
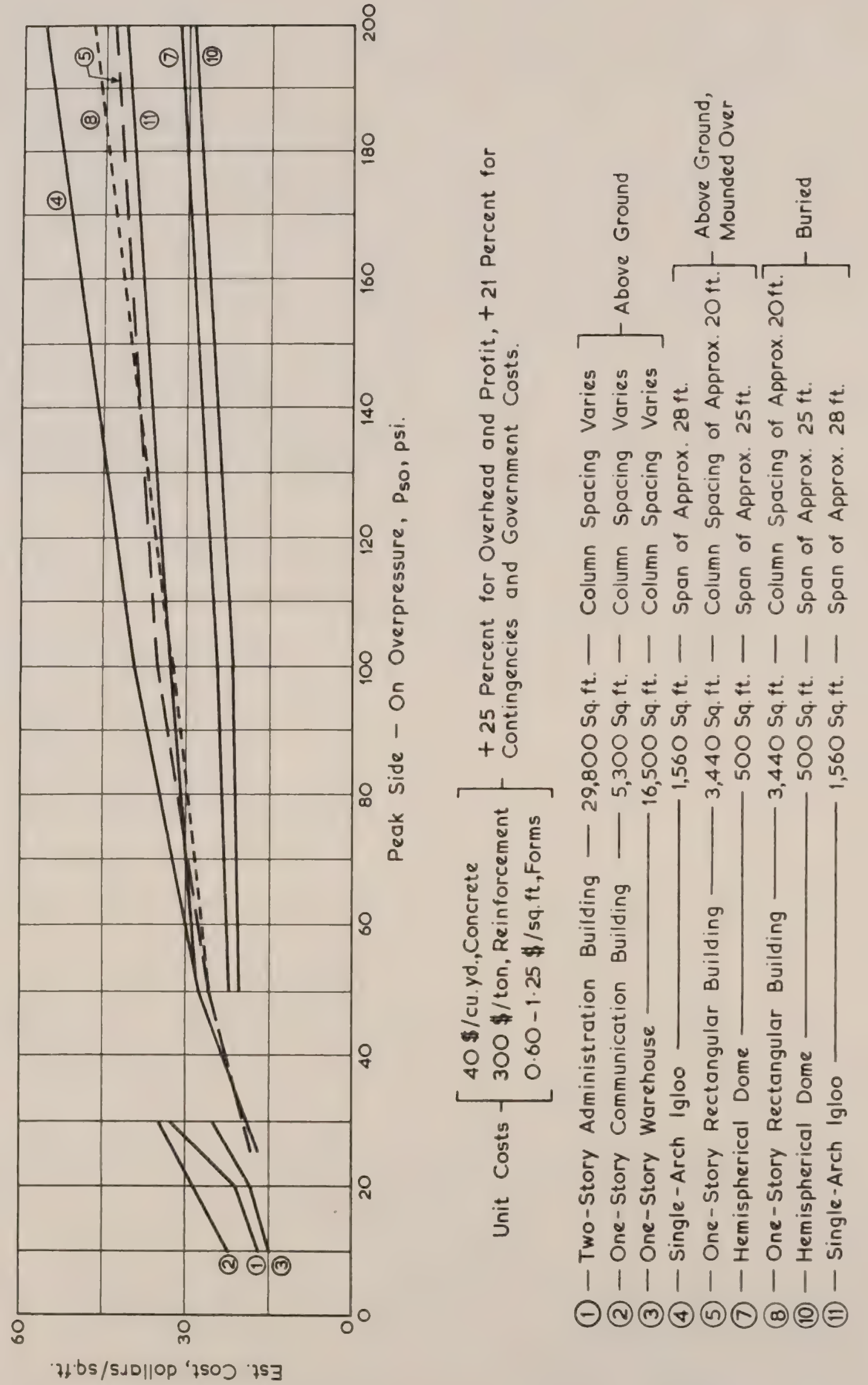
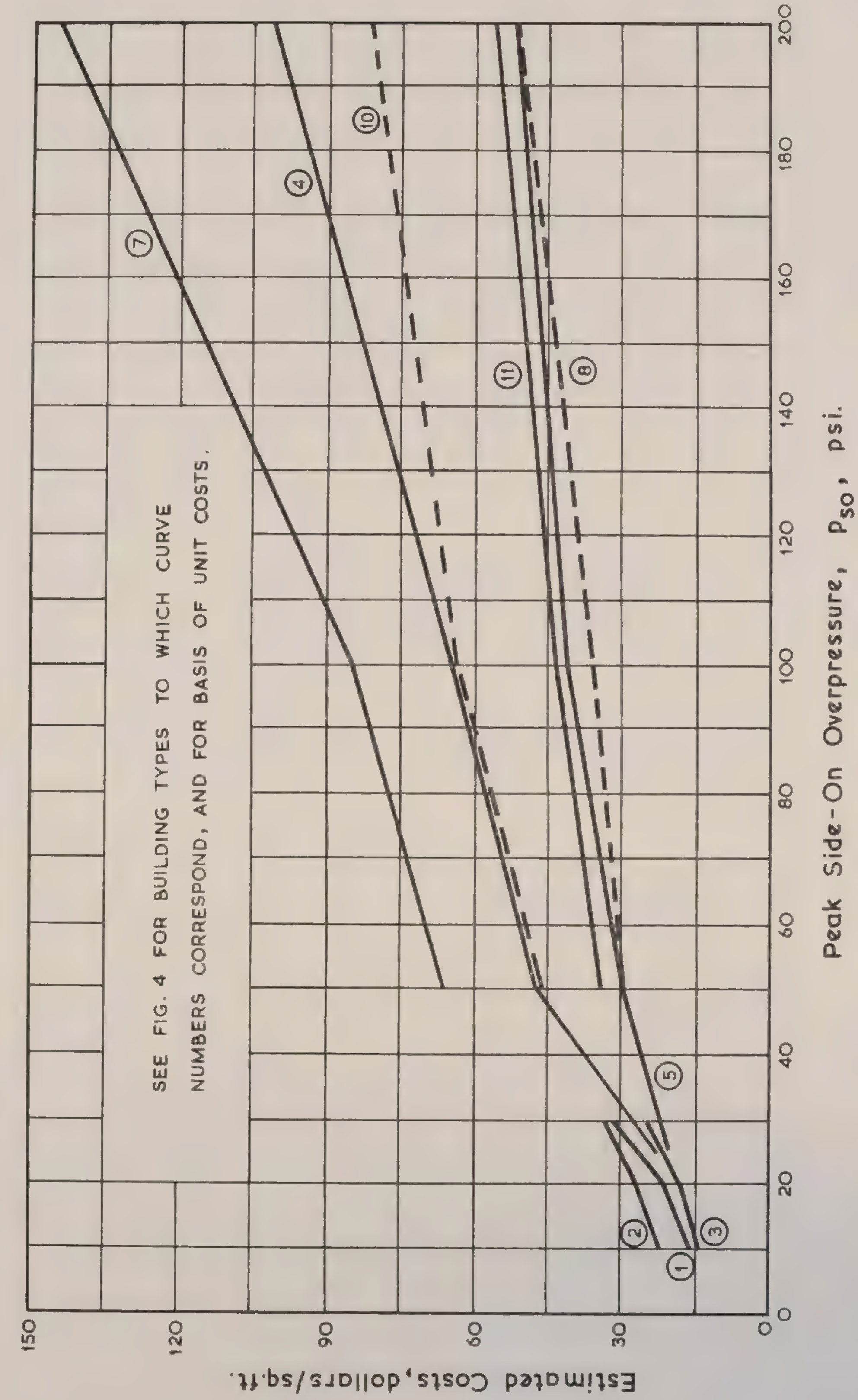


ATTENUATION OF FAST NEUTRON RADIATION —
BROAD BEAM IN THICK SHIELDS.

PART IV
CHAPTER 6
FIGURE 4

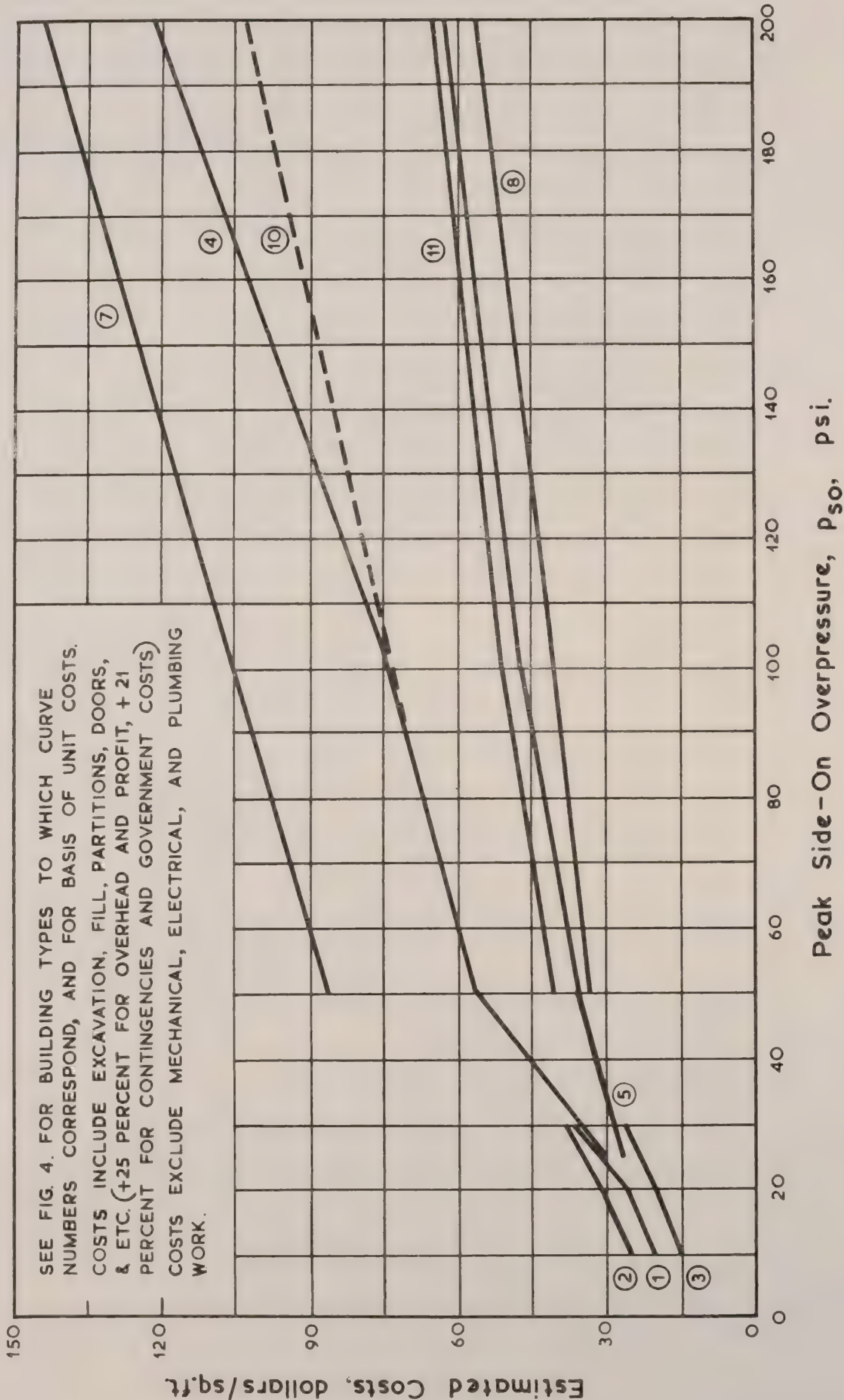


ESTIMATED COST OF BARE STRUCTURE, EXCLUDING ENTRANCE STRUCTURES

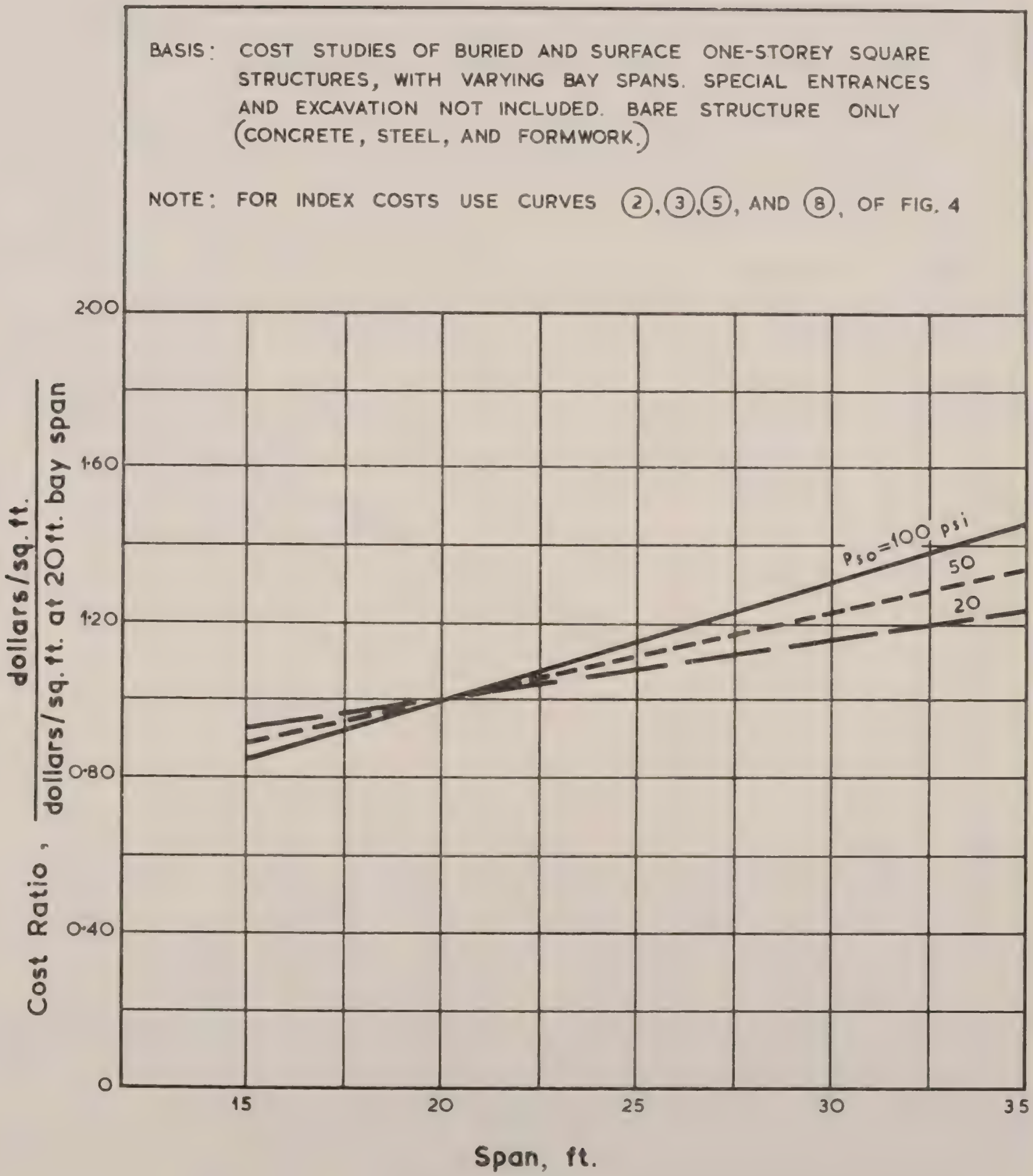


ESTIMATED COST OF BARE STRUCTURE, INCLUDING SPECIAL ENTRANCE STRUCTURES.

PART IV
CHAPTER 6
FIGURE 6



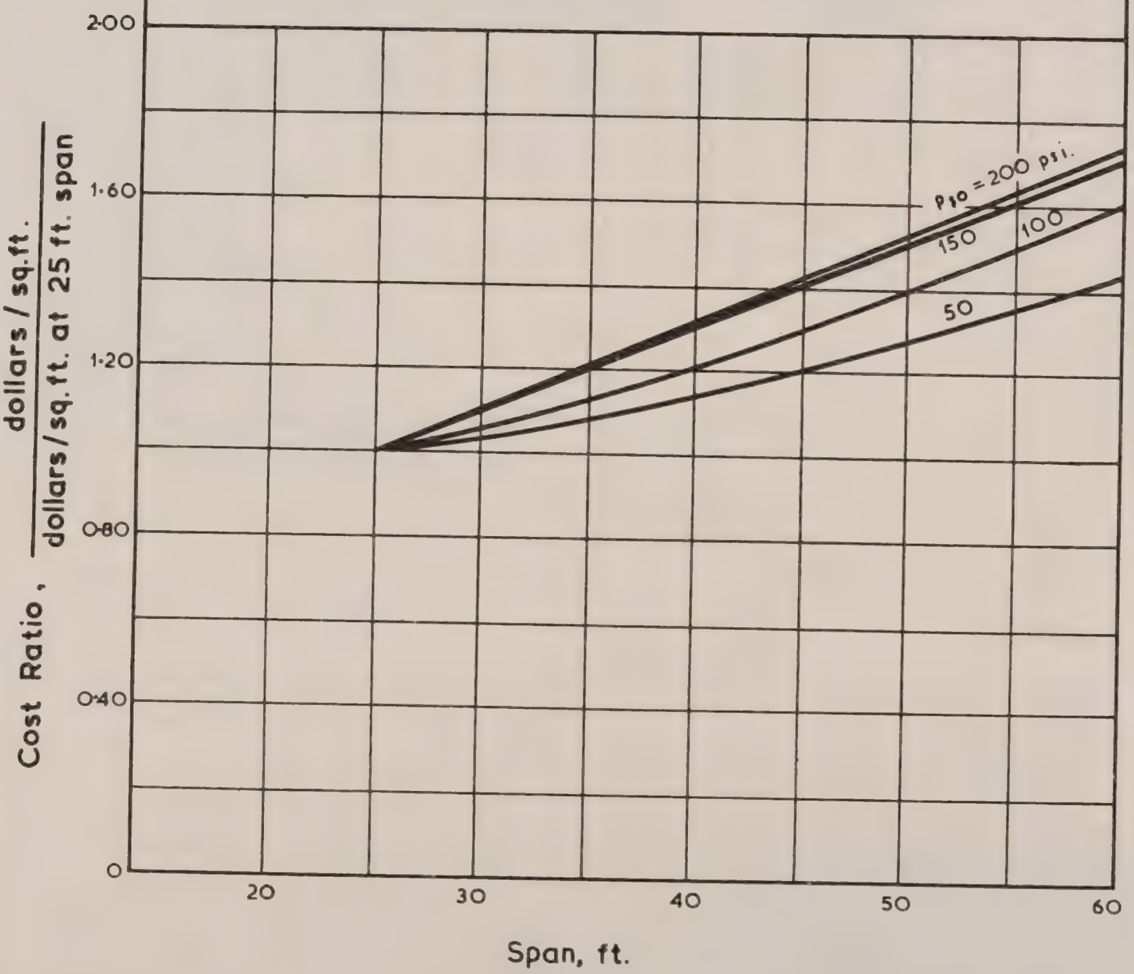
ESTIMATED COST OF STRUCTURES



COST RATIO VERSUS SPAN FOR ONE-STOREY RECTANGULAR STRUCTURES

BASIS: COST STUDIES FOR BURIED HEMISPHERICAL DOMES. SPECIAL ENTRANCES AND EXCAVATION NOT INCLUDED. BARE STRUCTURE ONLY (CONCRETE, STEEL, AND FORMWORK.)

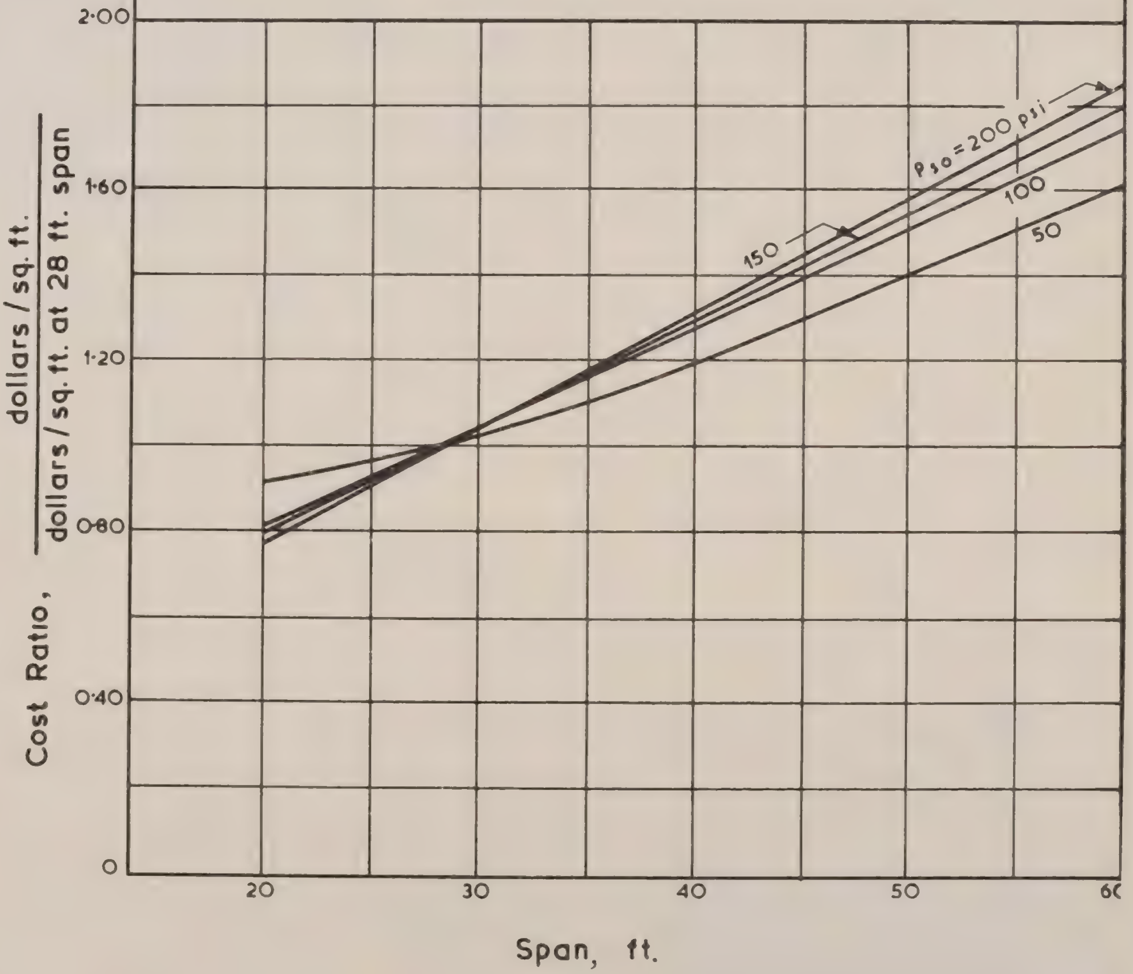
NOTE: FOR INDEX COSTS USE CURVES (7) AND (10) OF FIG. 4



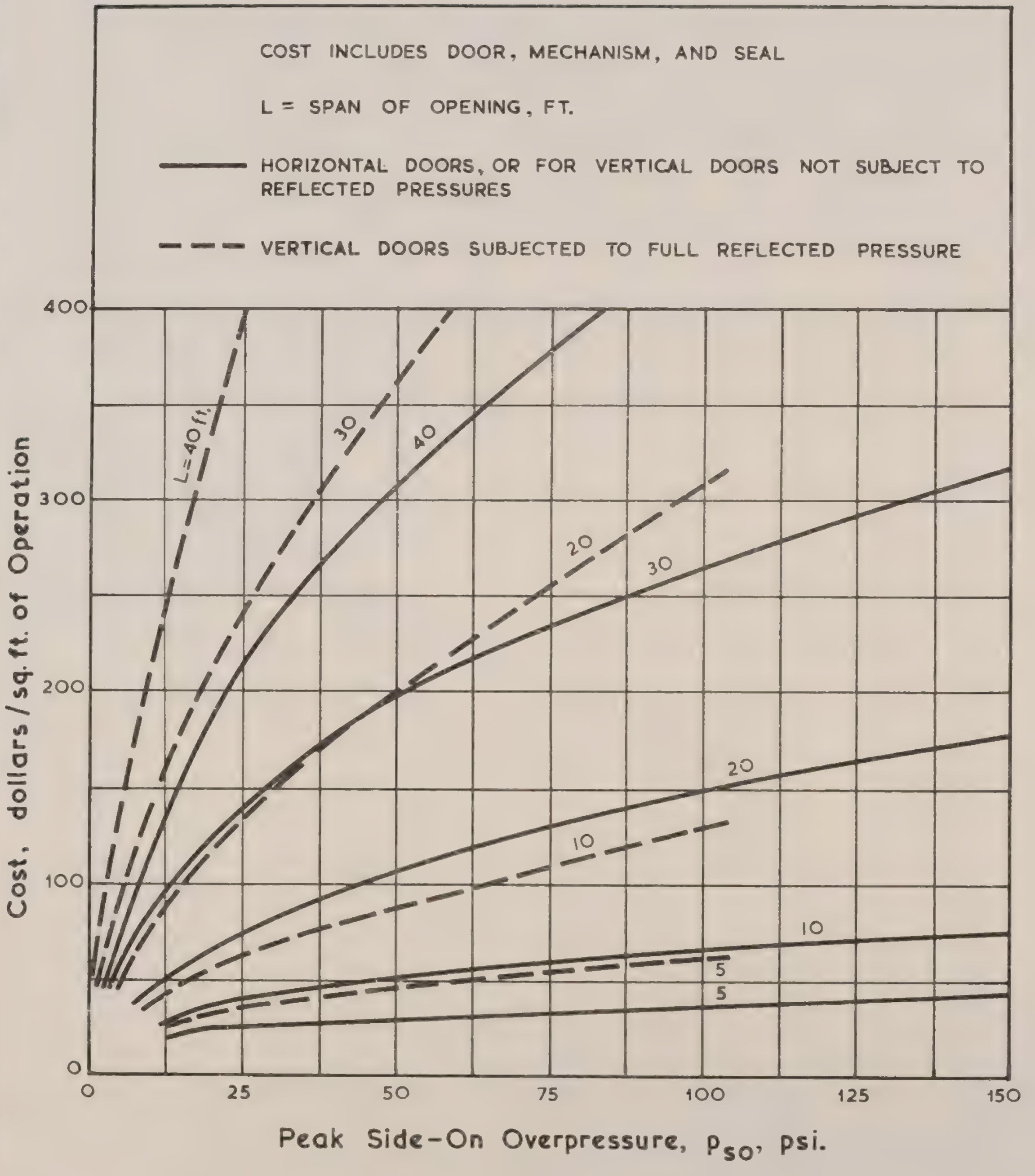
COST RATIO VERSUS SPAN FOR DOME STRUCTURES.

BASIS: COST STUDIES FOR BURIED, SINGLE-ARCH, IGLOO WITH LENGTH EQUAL TO TWICE THE SPAN. SPECIAL ENTRANCES AND EXCAVATION NOT INCLUDED. BARE STRUCTURE ONLY (CONCRETE, STEEL, AND FORMWORK.)

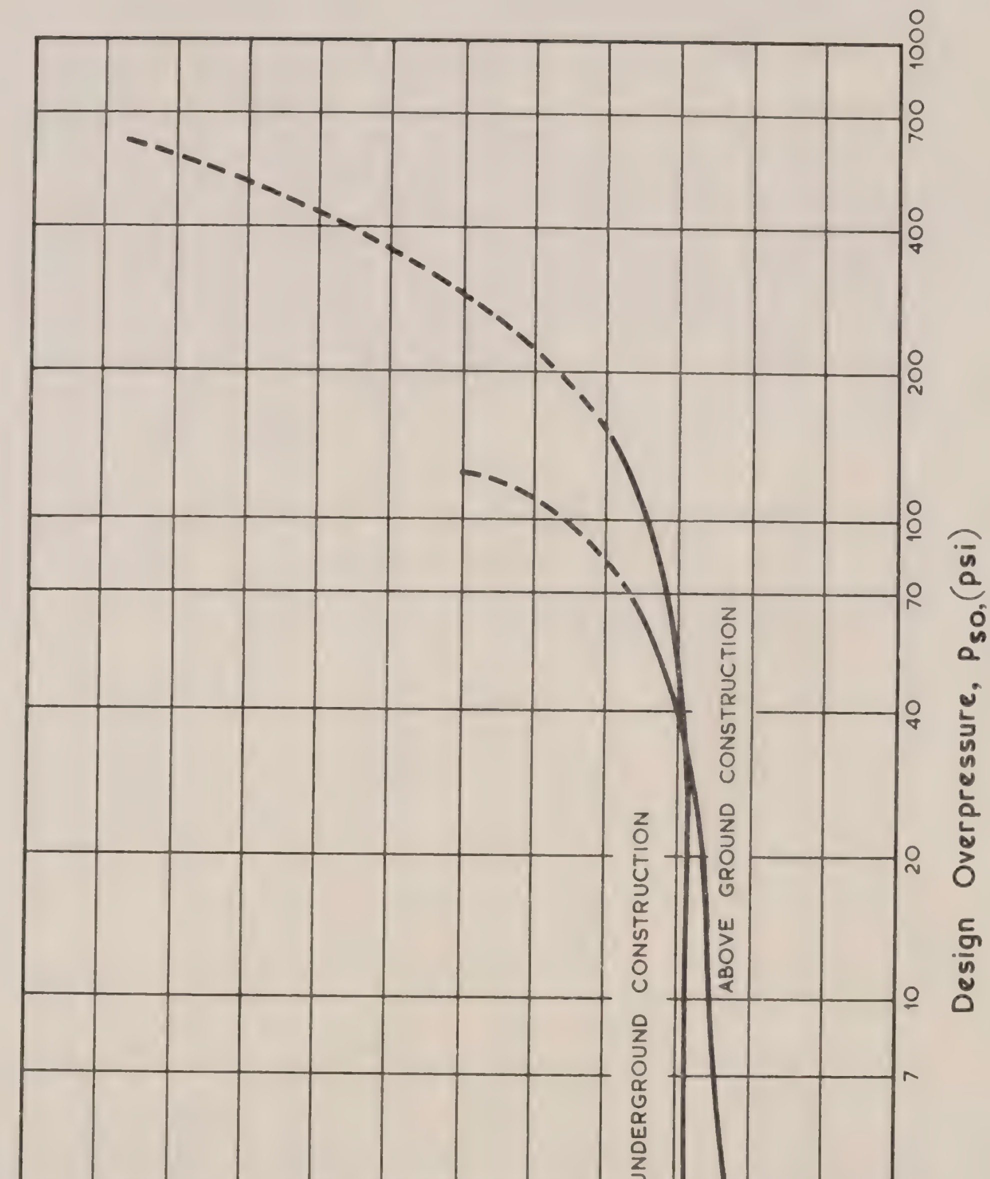
NOTE: FOR INDEX COSTS USE CURVES (4) AND (11) OF FIG. 4.



COST RATIO VERSUS SPAN FOR ARCH (IGLOO) STRUCTURES.



COST OF PROTECTIVE DOORS



RELATIVE COST OF CONSTRUCTION VS DESIGN OVERPRESSURE

CHAPTER 1 - INTRODUCTION

The explosion underwater of nuclear weapons results in a fireball composed of the vapourised bomb and vapourised water, at great temperature and pressure. The high pressure of the fireball generates a shock wave which radiates away from the point of detonation, and the fireball gases form a bubble as they expand against the hydrostatic pressure. At this stage the phenomena resemble those resulting from the underwater detonation of high explosives, and it is known from full scale trials that the shock wave and bubble effects at ranges of interest to target response can be described by substituting a T.N.T. charge of a given weight.

The shock wave and bubble pulse phenomena resulting from the underwater explosion of T.N.T. are well known and are described in detail in Data Sheet 4.2. etc. of the "Manual on the Effects of Atomic Weapons." For this reason only a very brief description of these phenomena is given below.

The shock wave in unrestricted water decays exponentially with time for at least one time constant and the peak pressure falls off with radial distance R as $R^{1.13}$

The pressure-time relationship for the shock wave in unrestricted water at a distance R (ft.) from the point of burst may be written

$$p_i = P_m e^{-t/\theta} \quad t \geq 0 \qquad (1)$$

$$p_i = 0 \quad t < 0 \qquad (2)$$

where p_i is the shock wave pressure at time t at a fixed distance R (ft.)

P_m is the peak shock wave pressure at this distance

$$P_m = (4.38)10^6 (W^{1/3}/R)^{1.13} \text{ (p.s.i.)} \qquad (3)$$

θ is the time constant (or decay constant)

$$\theta = (2.83)W^{1/3}(W^{1/3}/R)^{-0.18} \text{(m sec)} \qquad (4)$$

t is time measured from the time of arrival of the shock wave at the distance R in the same units as θ

It is of interest to note that, unlike the airburst case, the shock wave phase is associated with only positive overpressures. Much smaller negative overpressures of very long duration (can be longer than 1 second for 1 K.T.) associated with the overshoot of the gas bubble would occur in unrestricted water, but the mechanism of formation is rather different from that of the suction phase associated with an airburst. The long duration suction phase of an underwater burst will always be effectively destroyed by surface cut-off in practical cases.

Except in the anomalous region mentioned below the effect of the surface of the sea can be calculated by postulating an exactly similar but negative pressure pulse originating simultaneously at the image point of the detonation position with respect to the sea surface. The effect of this negative pressure is to reduce the shock wave pressure to zero at a time given approximately by (0.4)Dd/R milliseconds where D is the detonation depth, d is the depth of the point under consideration and R is the distance between the two, all measured in feet. The inability of sea water to withstand large tensions prevents the occurrence of significant negative pressures.

The impulse and energy in the shock wave passing a given point up to the time of cut-off are given by

$$I = (12.4)10^3 W^{1/3}(W^{1/3}/R)^{0.95}\left[1 - e^{-\tau/\theta}\right]$$

$$E = (3.94)10^8 W^{1/3}(W^{1/3}/R)^{2.08}\left[1 - e^{-2\tau/\theta}\right]$$

where I is the impulse (lb.sec/in^2)

E is the energy (ft.lb./in^2)

τ is the cut-off time (in the same units as θ)

For any underwater explosion there is always a distance from the explosion beyond which the propagation of the shock wave near the water surface ceases to obey acoustic theory and becomes anomalous. In this anomalous region the reflected wave catches up with the incident shock wave decreasing its peak pressure and lengthening its duration beyond the acoustic cut-off time. The ranges of interest to target response at Bikini BAKER were within the anomalous region, but for depths of burst greater than 200 $(W)^{1/3}$ (ft.) the pressure pulses capable of causing serious damage are unlikely to occur in the anomalous region.

The sea bed reflects the shock wave as a positive pulse but the phenomenon is complicated by the variable rigidity and lack of flatness of sea beds and the faster propagation of energy along sea bed material than in water. The importance of the sea bottom reflection is much less than that from the sea surface since the very maximum that it can do is to increase the effective charge weight by 100% (when the charge is exploded in contact with a perfectly rigid bottom). In practice, even for bursts on the bottom an enhancement of 50% is all that can be expected.

The refraction of shock waves due to sound velocity variations in oceans can lead to significant modification of the pressure pulse, compared to that in isovelocity water. The resulting pressure pulses can bear little resemblence to the original exponential form and regions of relatively low and high peak pressures are developed. The effects of refraction are of small interest for weapons of a few kilotons yield, begin to be significant at around 20KT, and are likely to be the dominating feature for megaton yields.

The fireball continues to expand after the shock wave has been generated and, provided that the depth of burst is sufficiently large, a maximum radius is reached without much vertical migration. At the maximum radius the pressure in the bubble is less than the hydrostatic pressure at the depth of its centre, and a contraction occurs. Inertia effects cause several pulsations to occur until venting at the sea surface occurs due to upward migration. Large vertical migrations occur during the periods when the bubble radius is small: for example, the upward migration at the first minimum for a 20 K.T. bomb detonated at 2,000 ft. is of the order of 300 ft. At its first minimum radius a pressure pulse is emitted which is an order of magnitude below that of the shock wave and subsequent pulses are of decreasing magnitude. The damaging power of the bubble pulses is small compared to that of the shock wave for the reasons given in Section (4.11).

Many other features of underwater nuclear explosions are associated with the bubble motion. Surface waves are formed in the process of filling in the depression created in the sea surface when the bubble vents. Water column formation is governed by the state of the bubble on venting, i.e. by whether the bubble radius is near a minimum or maximum, and cratering of the sea bottom is associated with bubble energy.

3.7 Experimental Data

The only full scale data on the effects of atomic weapons on surface ships is that obtained at Bikini Shot BAKER (4) where a 20 K.T. bomb was burst at 90 ft. depth in 180 ft. of water. This data is summarised in Figure (1). The peak underwater shock wave pressure values are not too helpful since the shapes and durations of the pulses are largely unknown. The trial geometry was such that anomalous propagation and bottom reflection were both significant.

Figure (1) shows that every class of ship was sunk within a horizontal distance from the burst of 550 yards. Also no class of ship would have sunk if manned beyond 550 yards. The limiting range for sinking of 550 yards is bracketed most closely for the attack transports and landing craft. The same limiting range for these two widely differing classes of ship give a convincing demonstration that for glancing angle attack the sinking distance is roughly constant for all classes of ship. The same conclusion appears to be valid for serious shock damage.

The lethal radius of submarines submerged to 80 ft. was greater than 900 yards. This is understandable since at this range the peak shock pressure was well in excess of twice the static collapse pressure of the submarines.

A considerable amount of experimental work has been carried out at U.E.R.D. on a 1/35th scale with models of a cargo ship and a cruiser using 106 lb. H.B.X.-1 charges. Little of this work has been reported but some analysed results are given in reference (5). Some of the more important experimental results are given in Table (1) together with values of E_V E_H E_T E_τ V_V and V_H.

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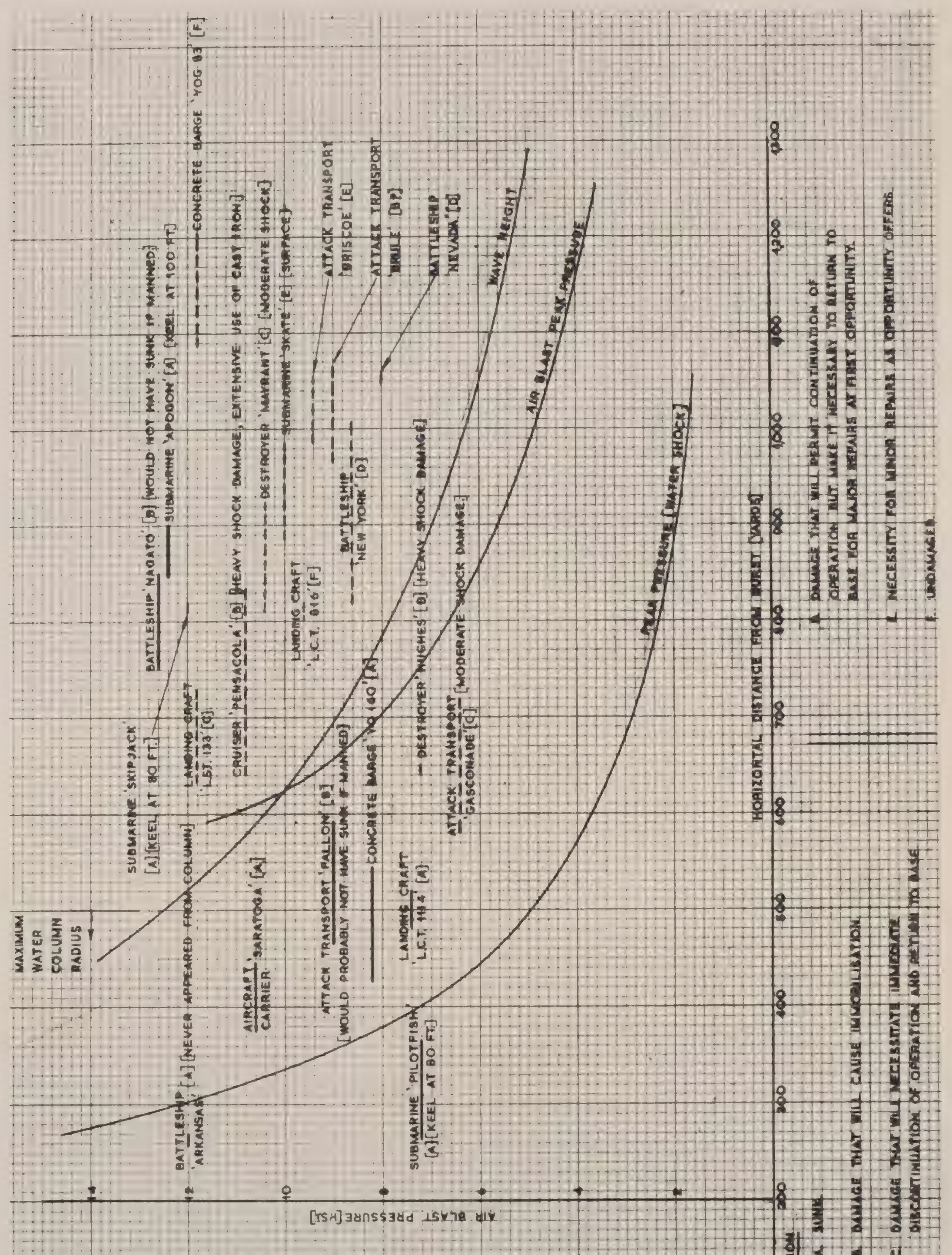

DATA FROM BIKINI

SHOT BAKER

SECRET

3.8 The Effect of Surface Waves on Surface Ships

At the ranges at which the underwater shock wave can do considerable damage the surface waves produced by underwater atomic explosions can be very large. The mechanism of wave formation is discussed in the British "Manual on the Effects of Atomic Weapons" where the following simple formulae are given for wave height etc.

Wave height (Crest to Trough) (ft.) = $(4.9)10^4 W^{1/2}/H$ (13)
Wave length (ft.) = $750\ W^{1/4}$ (14)
Group Velocity (ft./sec.) = $31 W^{1/8}$ (15)

where W is the Radio-Chemical Yield expressed in Kilotons of T.N.T. and a bubble equivalent energy of 0.86 W is assumed; H is the horizontal distance from ground zero (ft.). The above wave heights etc. apply when the weapon is exploded near to its venting depth given by

$$V = 240\ W^{1/4}\ \text{(ft.)} \qquad (16)$$

For shallower and greater depths of explosion the wave heights will be somewhat smaller except that for bursts very near the surface slightly larger waves may result.

It is of interest to examine the wave properties at the ranges of interest from the viewpoint of shock wave damage. Assuming that a value of $d/E = 7.10^{-4}$ is lethal for shock wave damage (see Section 3.3), the maximum horizontal range for sinking is given by -

$$H_{max} = 840\ W^{1/3} \quad \text{(assuming a shock wave equivalent weight of } \tfrac{2}{3}\text{ W)} \qquad (17)$$

This maximum horizontal range is obtained for a depth of explosion -

$$D_{max} = 570\ W^{1/3} \qquad (18)$$

At the range H_{max} the maximum wave height H_W is given by $H_W = (58.4)\ W^{1/6}$ (19) if the explosion takes place at a depth V where -

$$D_{max}/V = (2.37)\ W^{1/12} \qquad (20)$$

Numerical examples for several cases of interest are given in Table (I).

Section 3.8 Table (I)

Radio-Chemical Yield	Maximum Wave Height at Shock Wave Sinking Range (Crest to Trough) (ft.)	Wave Length (ft.)	Group Velocity (ft./sec.)	$\left(\frac{D_{max}}{V}\right)$
1 Kiloton	58	750	31	2.37
20 Kilotons	97	1,600	45	3.03
1 Megaton	185	4,200	74	4.22
20 Megatons	300	8,900	109	5.5

Ships are usually designed to have acceptable bending stresses when sitting symmetrically in quasi static equilibrium on a trochoidal wave with

with a wave length and wave height equal to the ship length and 1/20th of the ship's length respectively. The acceptable stress level is usually allowed to increase with the length of the ship and varies from 6 tons/sq.in. for small ships to 10 tons/sq.in. or more for large ships. This variation in acceptable stress allows for the fact that for very long ships say 800 ft. long, waves of 40 ft. high, say, are unlikely to occur and would in any case usually have a wave length greater than the ship length.

These considerations show that the wave heights given in Table (I) may well cause damage by excessive bending of the ship's hull. Detailed calculations of the bending moments are tedious and have not been carried out.

For ships riding on the top of waves, bending actions are likely to predominate. It may happen, however, that a ship plunges into an oncoming wave and in this case serious damage by swamping actions could conceivably occur. To examine this problem theoretically would be difficult, and there is a considerable need for experimental data on this problem.

Some experimental work on the problem of wave damage is in progress at the Naval Construction Research Establishment, but no results are available to date.

For References, see end of Chapter.

3.9 The Effect of Refraction

Using any of the criteria discussed above, the sinking radius increases as $W^{1/3}$ if the charge depth is increased as $W^{1/3}$. If the charge depth is kept constant, the sinking radius varies as $W^{1/4.33}$ using energy prior to cut-off as the criterion, and $W^{1/5.94}$ using a vertical bottom velocity criterion. It is clear therefore that the ranges predicted for megaton weapons are usually in the range 10 - 30,000 feet. In such cases the refraction effects discussed in Section 4.10 can be expected to play a significant part, particularly at the larger ranges. The prediction of pressure histories, and hence of damage to surface ships in heavily refracted regions is not possible at present, but experimental and theoretical work is being carried out in both the U.S.A. and the U.K. This work should eventually make possible the prediction of pressure histories and any of the damage criteria discussed above will be applicable to the pressure pulses obtained.

Ray theory is adequate for assessing the importance of refraction. It is likely that refraction will be of little importance for Kiloton weapons and of far less importance with megaton weapons than is to be expected for submerged submarines, which have far larger damaging ranges.

For References, see end of Chapter.

3.10 Shock Damage to Surface Ships

Damage to machinery etc. by shock is governed mainly by the velocity acquired by the ship's bottom. This velocity can be calculated using figure (1) Section 3.5, bearing in mind that the actual velocity acquired will probably exceed this theoretical value by about 40% (see Section 3.7). The following rough estimates can be made of the effects to be expected at various bottom velocities:

(i) 30 ft./sec. Bottom Velocity

Very severe shock damage leading to immobilisation.

(ii) 20 ft./sec. Bottom Velocity

Severe shock damage to all but the most rugged equipment, possibly leading to immobilisation in warships and almost certainly leading to immobilisation in merchant ships.

(iii) 10 ft./sec. Bottom Velocity

Moderate Shock Damage. Main propulsive machinery probably still operable if designed or suitably protected to withstand shock. A lot of damage to electronic equipment etc.

(iv) 5 ft./sec. Bottom Velocity

Light damage probably confined to electronic equipment lighting fittings etc.

Curves of $H/W^{1/3}$ against $(D-d)/W^{1/3}$ for the above 4 categories of damage are given in figure 1. Comparing these curves with those giving hull splitting ranges shows that severe shock damage will usually occur at ranges greater than those at which hull splitting occurs.

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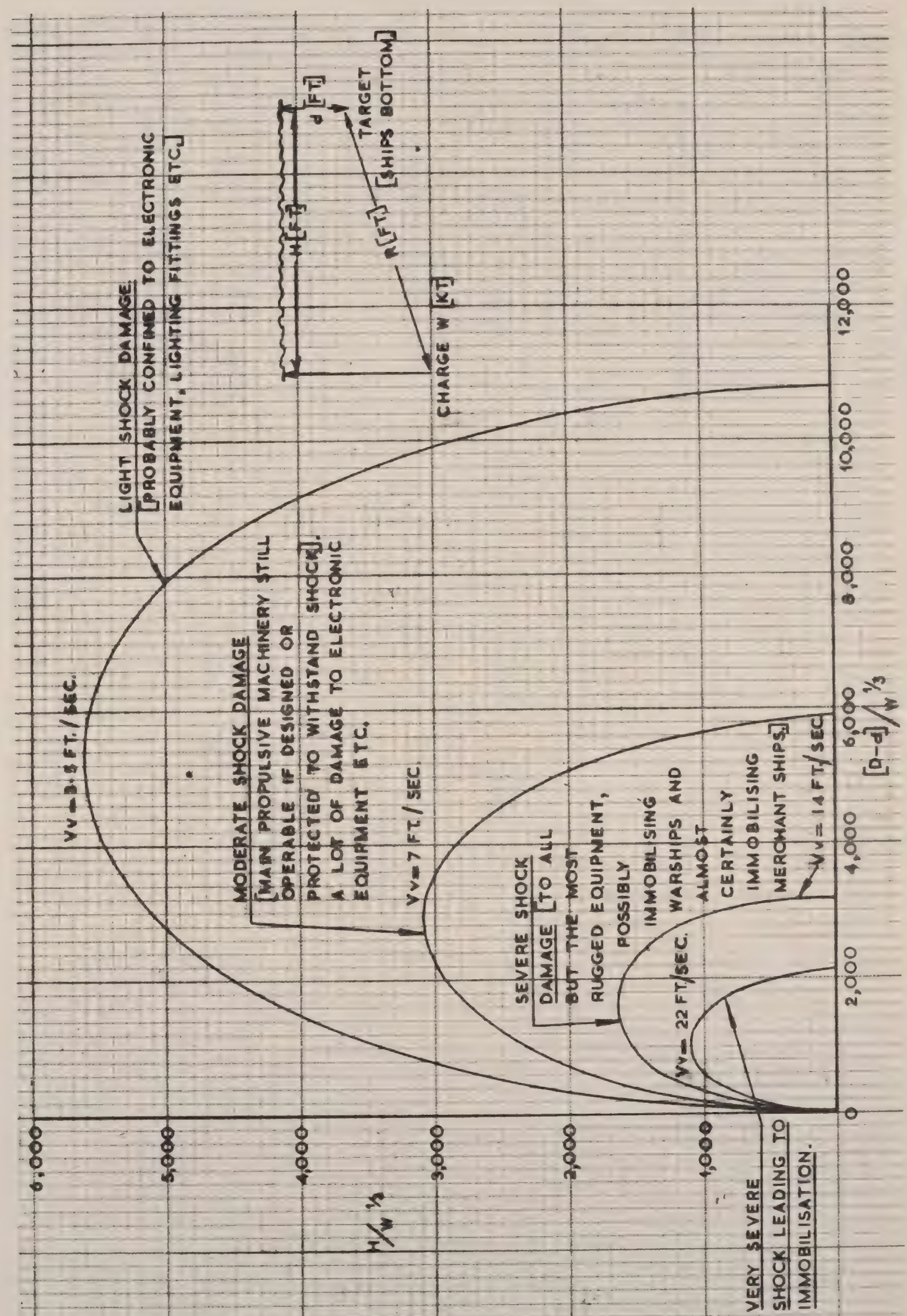


SHOCK DAMAGE CURVES
FOR SURFACE SHIPS

CHAPTER 4 - DAMAGE MECHANISMS FOR SUBMERGED SUBMARINES

4.1 The Types of Damage

The damage to submarines caused by underwater explosions from conventional and atomic weapons falls into two fairly distinct types. Firstly the general shaking up of the submarine caused by the shock wave can cause machinery to be displaced or damaged so as to impair the operation of the submarine sufficiently, in severe cases, to cause complete loss. This type of damage is generally referred to as shock damage and can be reduced by the improved design of machinery and mountings. No matter how shock resistant a submarine is made, however, a point is reached as the charge standoff is reduced when hull splitting or gross deformation results which will usually result in the complete loss of the submarine. The standoff at which this occurs, often referred to as the lethal radius, is of particular interest and will be considered first.

The problem is one of considerable difficulty and several lethality criteria based on entirely different collapse mechanisms have been suggested and are more or less tenable. As all of the criteria are based on highly simplified mathematical models, their validity depends upon their agreement with experimental results. Unfortunately insufficient experimental results are available at present to enable any of the criteria to be rejected. These criteria will be described briefly with a discussion of their shortcomings.

4.2 The Mechanism of Hull Splitting

For a deep burst against a deep submarine, when surface cutoff can be neglected, the shock wave from an atomic explosion is quite long compared to the diametral or compartment length of a submarine. This is illustrated in figure (1), where the pressure distance relationship for the shock wave from an explosion of 1.5 K.T., 30 K.T. and 1.5 M.T. Radio-chemical Yield is given for the ranges corresponding to a peak pressure of 1,000 p.s.i. The pressure decays rather little over a range equal to a diameter or compartment length, so the submarine is soon bathed in an almost uniformly high pressure which decays exponentially with time. Since the time constant of the decay is several times greater than the natural period for hull radial vibrations, this may suggest at first sight that when cutoff is not important, the loading may be considered as effectively static. Thus it may be expected that collapse will occur when

$$P_m + P_o = P_c$$

where

P_m is the peak shock wave overpressure
P_o is the hydrostatic pressure at the depth of the submarine
P_c is the static collapse pressure of the submarine.

The problem is not so simple however for the following reasons;

(a) The question of a dynamic factor has to be considered since the loading is suddenly applied. If, as for linear springs under suddenly applied constant loading, the dynamic factor is 2 then yielding and possibly collapse could occur when

$$2 P_m + P_o = P_c$$

/(b)

(b) Rupture of the hull will only occur if sufficient damage is inflicted by the shock wave loading either to cause hull splitting directly or to reduce the submarine strength below that necessary for withstanding the hydrostatic pressure. To cause this amount of damage will normally take several milli-seconds, so just to reach yielding instantaneously in the structure is unlikely to be a sufficient criterion for collapse;

(c) The loading is sufficiently rapid for a dynamic enhancement of the yield stress to take place in most materials.

The question raised in (a) above can only be resolved by studying in detail the response of a cylindrical pressure hull to a slowly decaying shock wave. This problem has been studied by several authors, (References 1, 2, 3, 4, 5) and particular attention has been paid to the case of side-on attack for which several phases occur. The shock wave first hits one side of the section and a reflected wave is generated as the wave front traverses the cylinder. The incident plus reflected pressures cause motions of the hull which in turn induce a relief pressure to be formed at the pressure hull surface and radiated into the surrounding water. The response is rather complex but can be calculated by solving the wave equation in cylindrical co-ordinates with appropriate boundary conditions on the cylinder. The problem is far more difficult than that of a plane wave hitting a plane air backed plate as discussed in Chapter 2, since the relief pressure depends upon the whole time history of the hull motion and not on the instantaneous velocity. For this reason only brief results of some calculations carried out on this problem are presented below.

The radial displacement of the pressure hull for side-on attack can be expressed as the sum of a cosine series:-

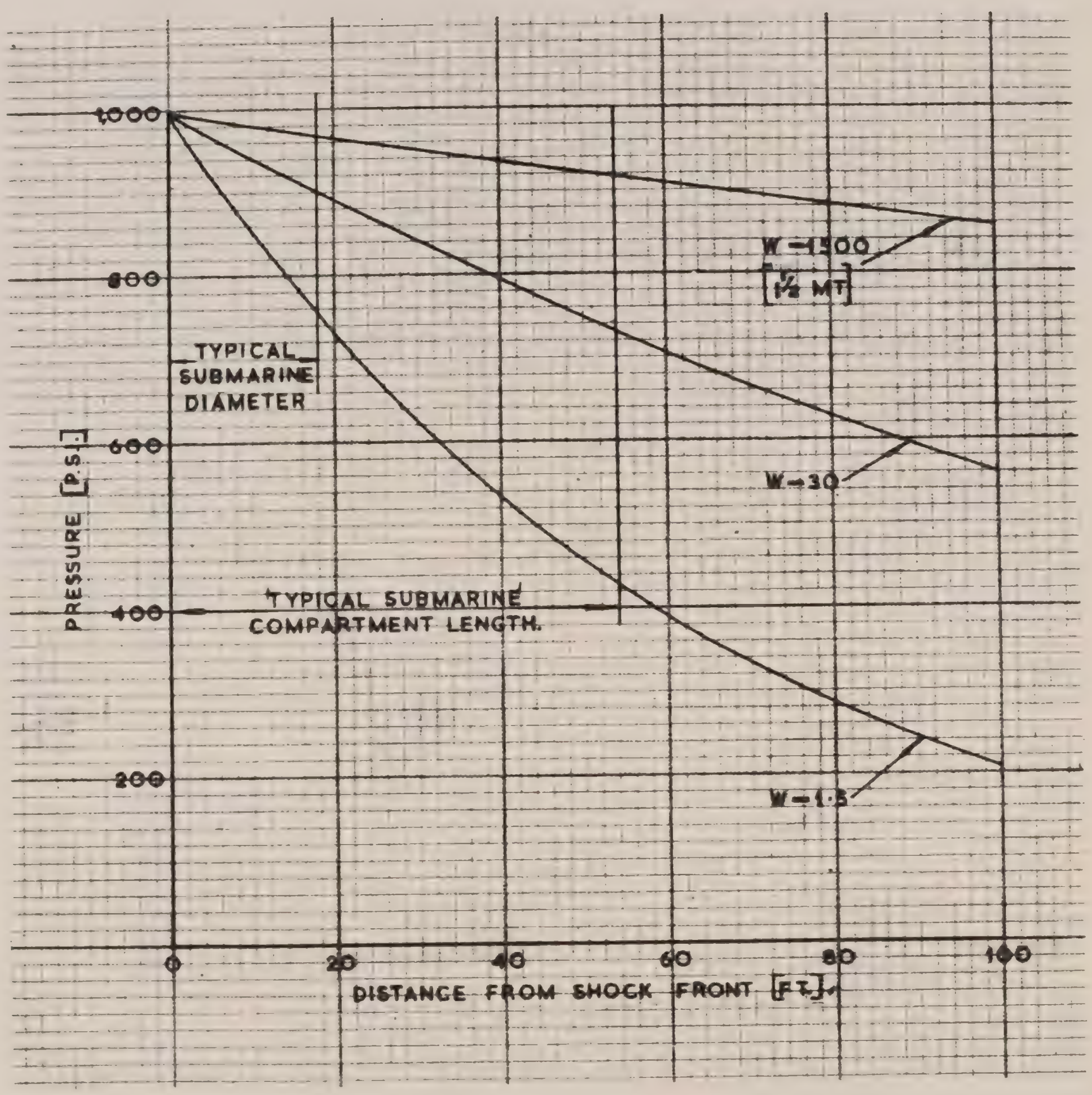
$$w(\theta,t) = w_0(t) + w_1(t)\cos\theta + w_2(t)\cos2\theta$$

The uniform radial displacement mode $w_0(t)$ is of considerable interest since it is the mode of static deformation and the static collapse pressure is associated with an easily calculated value of this mode. The calculated time history of the uniform radial displacement for a shock wave of time constant 23.8 milliseconds (4,100 ft. from a 10 K.T. burst) impinging side-on to an elastic steel cylinder of radius 100 inches and thickness 1 inch is given in figure (2a). Also given in figure(2a), for comparison, is the static deflection corresponding to the value of the incident pressure at the diametral points A and B. It can be seen that the maximum of the dynamic deformation curve is only 87% of the quasi-static curve maximum. The reason for this lack of overshoot for the case considered is that the relief pressure acts as a damping force of a magnitude that for this mode is nearly critical. A small overshoot of about 5% can occur for more slowly decaying pulses such as are obtained from megaton weapons.

The $w_1(t)\cos\theta$ component of the dynamic displacement fixes the rigid body motion, and is of considerable importance for shock damage studies. The calculated time history of the rigid body mode velocity for a neutrally buoyant cylinder of radius 100 in. attacked side-on by a shock wave of time constant 23.8 milliseconds (4,100 ft. from a 10 K.T. burst) is given in figure (2b). Also shown in figure (2b) for comparison is the particle velocity in the undisturbed shock wave at the diametral points A and B. As might be expected the cylinder velocity never exceeds the particle velocity in the shock wave but acquires very nearly this particle velocity in about 3 transit times (one transit time is the time required by the shock wave to travel over a distance equal to one submarine diameter.).

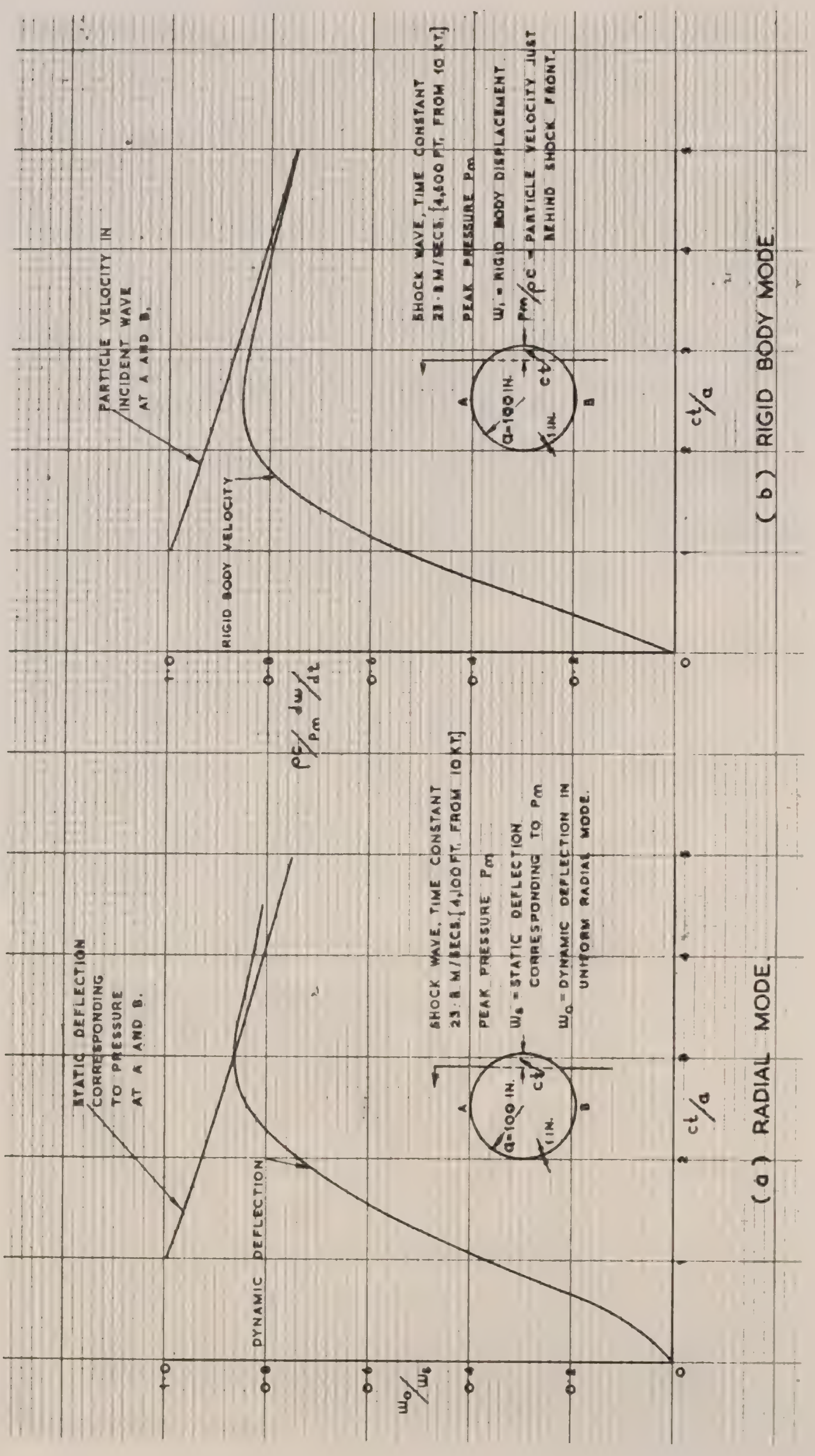
The deformation modes associated with circumferential bending of the hull, $W_2(t)\cos 2\theta$, $w_3(t)\cos 3\theta$ etc. can also be evaulated and several cases of interest have been evaulated in reference (5).

The elastic analysis although complicated can be carried out to any desired accuracy, and has a direct bearing on the problem of shock damage to equipment. The relevance of elastic analysis to the question of plastic collapse is not so clear, except for the understanding which the results give of the degree of hydrodynamic damping to be expected. It is interesting, however, that a lethality criterion has been proposed (6) which uses only elastic analysis and which gives results agreeing quite well with results obtained from an extensive series of small scale experiments. This criterion is described in the next section.



PRESSURE-DISTANCE RELATIONSHIPS FOR DEEP BURSTS AGAINST DEEP SUBMARINES

CONFIDENTIAL



THE RESPONSE OF AN ELASTIC CYLINDER TO AN EXPONENTIALLY DECAYING PLANE SHOCK WAVE

CONFIDENTIAL

4.3 The delayed Yield Criterion

Gooding and Sette (6) have proposed that the collapse of pressure hulls under dynamic loading may be governed by the delayed yield phenomenon which is observed in steel. It is found that when a steel specimen is loaded very rapidly, elastic stresses greater than the static yield stress can be maintained for very short times; the higher the applied stress the shorter the time. A typical delayed yield curve for the submarine steel HTS is shown in figure (1).

An elastic response analysis is carried out for the uniform radial displacement mode allowing for the presence of the ring stiffeners by an increased plating thickness. The circumferential stress is plotted against time as shown in figure (2) and the time at which the dynamic plus the static stress is equal to the static yield stress determined. For subsequent times the average stress is evaluated as a function of T (see figure 2) and plotted on the same co-ordinates as the delayed yield stress curve. Typical curves for two values of P_m are shown in figure (1).

Gooding and Sette have postulated that collapse will occur only if the curve of average stress against T lies above the delayed yield curve at some point. The lethal standoffs deduced from this hypothesis were shown to agree quite well with experimental results obtained in a series of small scale trials (6) (7).

These model tests were carried out over a wide variation in depth and for a wide variety of materials - mild steel, Carbon-Molybdenum steel, high tensile steel, special treatment steel and Aluminium alloy. For each material and over a wide depth range it was found that lethality was associated with a constant value of the ratio

$$P_r = (P_o + P_m)/P_c$$

The experimental data is summarised in figure (3) where values of static collapse pressure P_c and lethal values of $P_m + P_o$ are plotted against yield stress. It is very noticeable that for the steel models, the ratio of dynamic collapse pressure to static collapse pressure decreases from 2.3 to unity as the yield stress increases from 25,000 p.s.i. to 100,000 p.s.i. Gooding and Sette attribute this to the progressively reduced dynamic enhancement of the yield stress as the static yield stress increases. Other explanations are possible (see below). The reduction in dynamic compared to static collapse pressure in the case of the Aluminium alloy models is explained by the very small dynamic enhancement for this material and elastic overshoot due to subcritical damping.

If the delayed yield criterion is generally valid it is clear that model experiments can give results directly applicable to full scale only if the dynamic enhancement of stress plays a small part on model scale. This is because the rapidity of loading is greater on the model than on the full scale so that a greater dynamic enhancement of yield is obtained on the model scale. Another conclusion would be that increases in the static collapse depth of submarines obtained by using steel of increased static yield stress would not lead to a proportional increase in lethal radius. This is because in general the higher the yield stress of a steel the smaller is the dynamic enhancement for a given rate of loading.

Although the delayed-yield criterion explains adequately the experimental results of Gooding and Sette, the following objections can be raised

(1) The method is very sensitive to the delayed yield curve. This curve is not too well defined and data from different investigators deviate considerably.

(2) The decreasing value of P_r for increasing yield stress can be at least partly explained by the fact that keeping the dimensions constant and increasing the yield stress leads to models of unbalanced design with relatively weak frames. This could be expected to lead to poor dynamic performance.

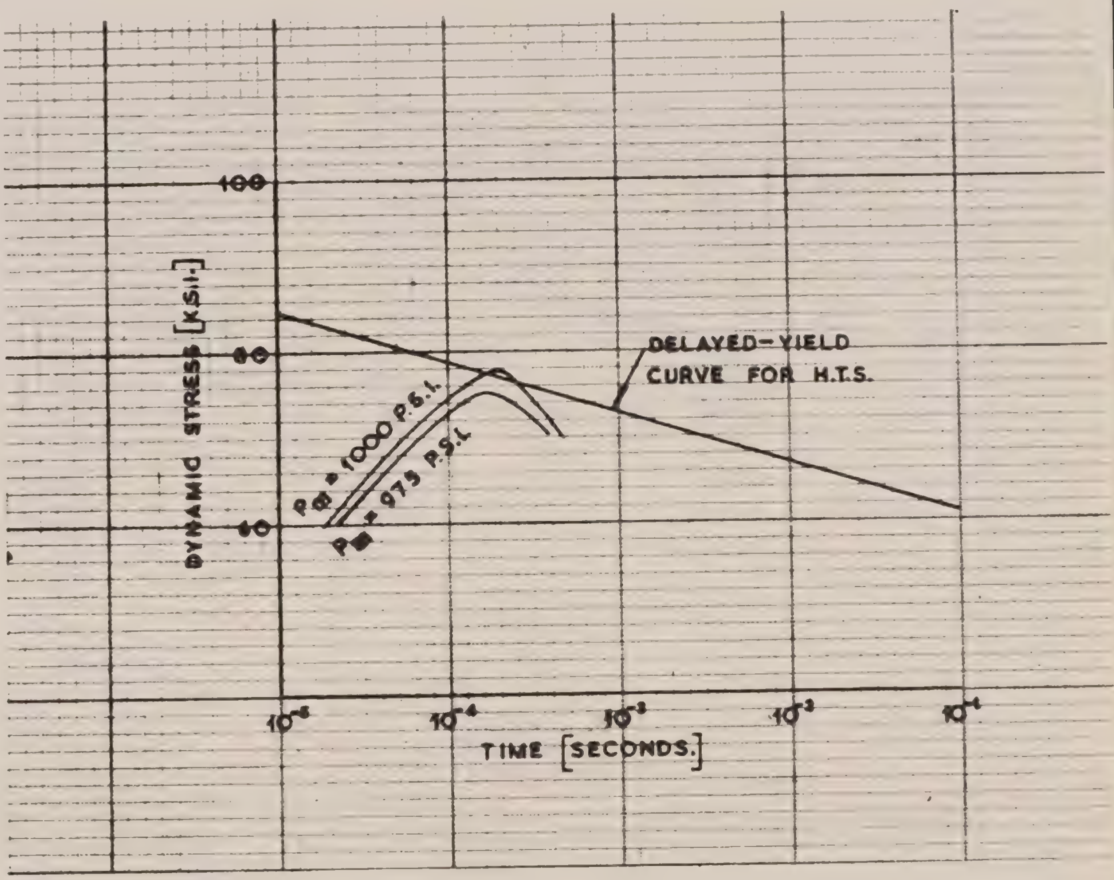
(3) Strain hardening and strain rate effects can be expected to play a part but these are neglected.

(4) Delayed yield may well not occur at all in full scale welded structures.

(5) The mean deflection at the instant when the mean stress versus T curve touches the delayed-yield curve is much less than one plating thickness whereas deformations of several plating thicknesses are necessary for rupture.

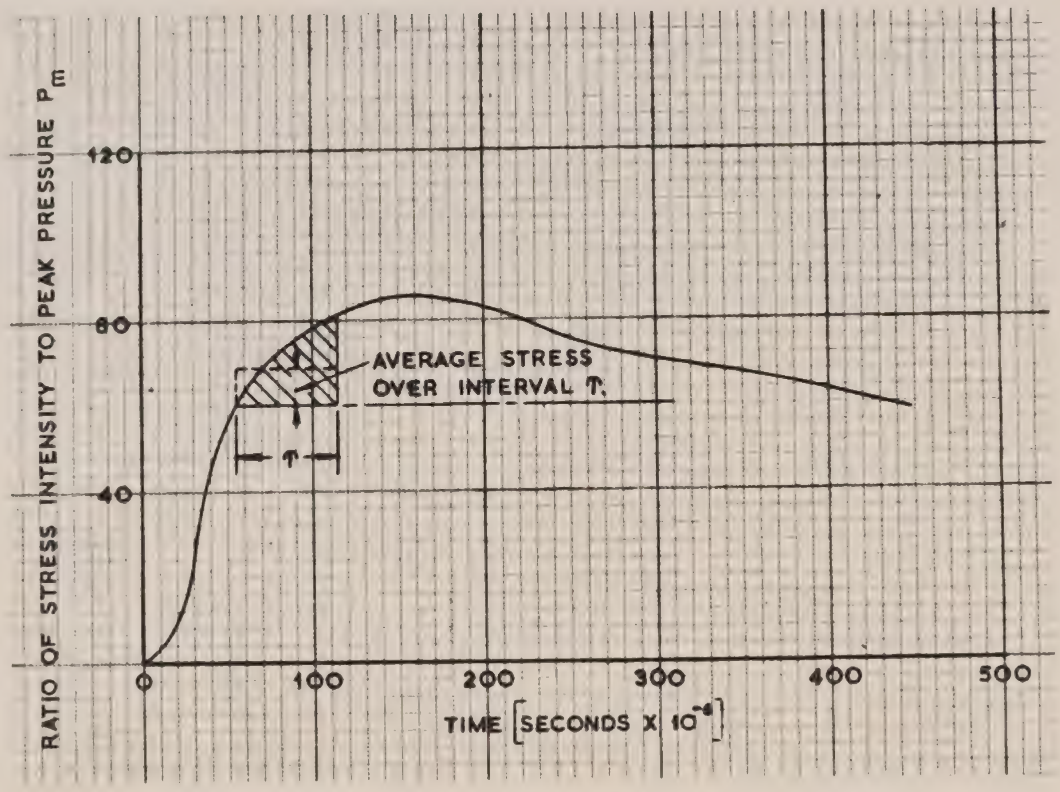
(6) The bending stiffness of the frames is known to play a significant part in explosion resistance but is not allowed for in the criterion.

For References see end of Chapter.

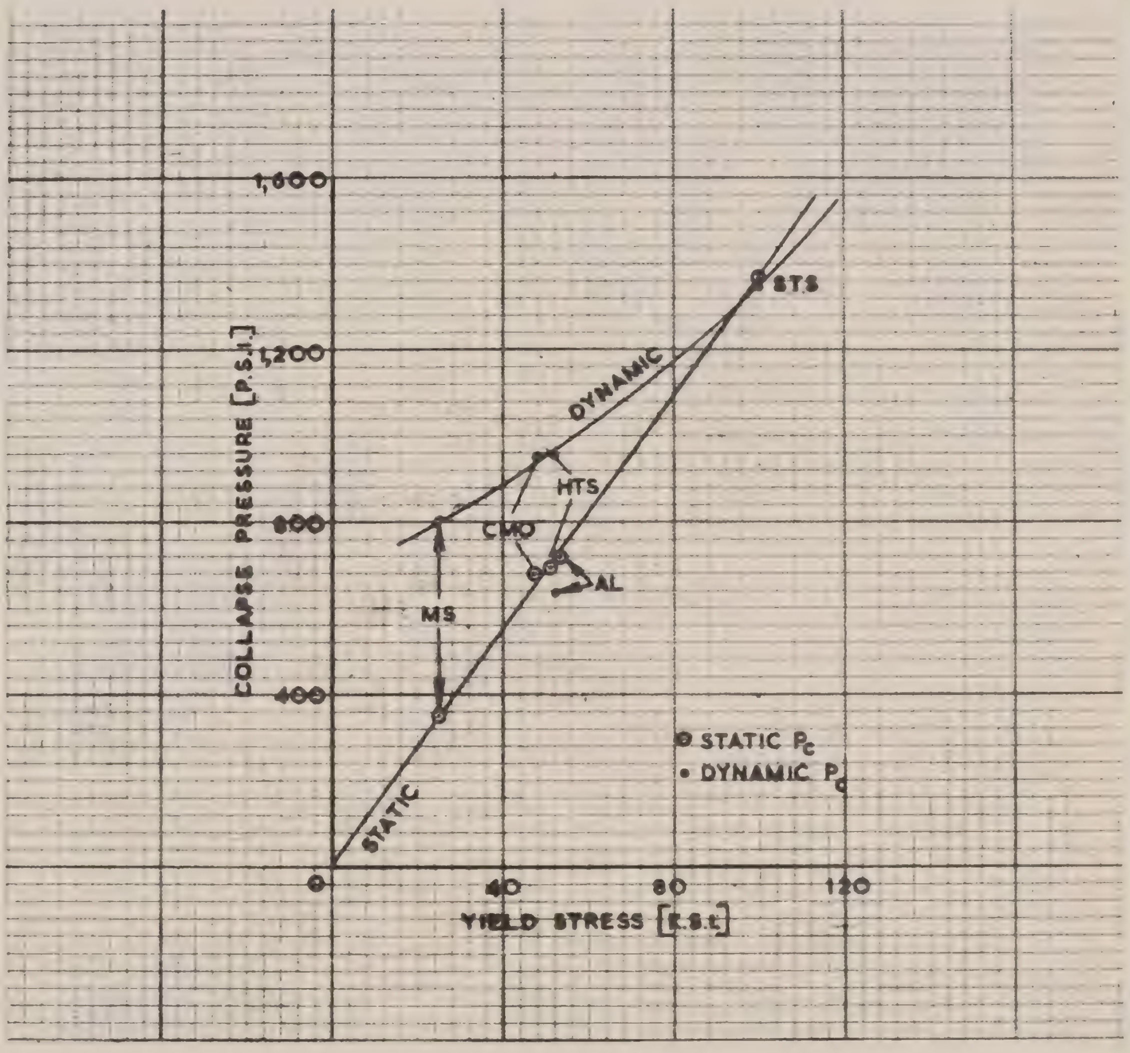


DELAYED YIELD CURVE FOR
SUBMARINE STEEL

PART V
CHAPTER 4
SECTION 4.3
FIGURE 2



CIRCUMFERENTIAL STRESS OF SUBMARINE
STEEL AS A FUNCTION OF TIME



STATIC AND DYNAMIC COLLAPSE PRESSURES
AS FUNCTIONS OF YIELD STRESS

4.4 Elastic-Plastic Response of Cylindrical Shells to Shock Waves

From the mathematical viewpoint it is not necessary to confine response calculations to the purely elastic phase. Provided that the relation between stress, strain and strain rate are known beyond the elastic limit the calculations can be carried into the plastic region. Using the full hydrodynamic equations this would be difficult, but Haywood (5) has developed a simple method of solution which gives accurate answers. Considering only the uniform radial displacement mode the governing differential equations for the motion of the cylinder can be written

$$m\ddot{w} + \sigma h/a = P_o + P_i - P_r \qquad (1)$$

$$\dot{w} = P_r/\rho c + \left(\frac{0.363}{\rho a}\right)\int_0^t P_r dt \qquad (2)$$

where m is the mass/unit area of the shell plating

- h is the shell plating thickness (in.)
- a is the mean shell radius
- ρ is the density of water
- c is the velocity of sound in water
- w is the displacement radially inwards
- P_i is the incident shock wave overpressure
- P_o is the static pressure
- P_r is the relief pressure
- σ is the stress in the shell plating (a function of w and possible $\dot{w}$)

Neglect of the inertia terms $m\ddot{w}$ leads to errors only at very small times.

The equations can be solved numerically in any particular case and the evaluation of a large number of cases taking different stress-strain/strain-rate relationships would give a much better understanding of the response mechanism. Unfortunately this would be very time consuming without electronic computing and has not been attempted. Another snag is that little is known about the relation between stress-strain and strain-rate for steel.

Since a purely theoretical solution to the problem of submarine lethality is not at present possible, it is necessary to resort to semi-empirical rules based on highly simplified mathematical models. The justification for the use of these rules lies almost entirely in their agreement with experimental results.

4.5 The Excess Energy Criterion

It is obviously worth considering whether the lethal severity formulae for conventional weapons still hold for atomic weapons. A very well known equation for conventional charges against shallow submarines with a yield stress of about 18 tons/sq.in. is the Hogg formala.

$$w = (0.75)hR\sqrt{R^2 + 110} \simeq (0.75)hR^2 \text{ for large charge weights} \qquad (3)$$

where h is the shell plating thickness (in.)

w is(the charge weight expressed in lb. T.N.T.
R is the lethal standoff (ft.)

When modified to allow for depth of submergence and yield point variation the Hogg formula for large charges becomes

$$w = (0.75)h(\sigma_y/18)R^2[1 - (P_o/P_c)^{3/2}] \qquad (4)$$

where σ_y is the yield stress (tons/sq.in.)

P_o is the static pressure
P_c is the static collapse pressure

For a given submarine at a given depth the lethal radius given by (4) varies as $w^{\frac{1}{2}}$. Thus, since the peak shock wave pressure is proportional to $(w^{1/3}/R)^{1.13}$, the peak pressure at lethality is proportional to $W^{-1/4.3}$ and eventually for large charge weights drops to values less than the collapse pressure margin $P_c - P_o$. This shows that equation (4) cannot be true for very large charge weights. The physical explanation is that equation (4) is based on the assumption that a constant value of the energy flux

$$E = \int_{0}^{\infty} (P_i^2/\rho c)dt \qquad (5)$$

is required for lethality. For the long duration shock waves obtained from atomic explosions the required value of energy flux can be obtained with relatively low peak pressures.

This difficulty can be overcome by considering only the energy flux up to the instant when the shock wave equals the collapse pressure margin $P_c - P_o$. The equation then becomes

$$w\left\{1 - \left(\frac{P_c - P_o}{P_m}\right)^2\right\} = (0.75)h(\sigma_y/18)R^2[1 - (P_o/P_c)^{3/2}] \qquad (6)$$

and it can be seen that the following limiting values hold

$P_m = P_c - P_o$ as $W \to \infty$

$R \to \infty$ as $P_o \to P_c$

The first limiting value is probably very nearly correct since very little dynamic overshoot may be expected. The second limiting value is obviously correct. Unfortunately another objection exists against both equations (4) and (6) which can best be discussed by means of a numerical example as follows.

For a submarine with a collapse pressure of 500 p.s.i. at a depth of 500 feet with a pressure hull thickness of 1 inch and a yield stress of 27 tons/sq. in. equation (4) gives

/R =

$R = (1.13)w^{\frac{1}{2}}$

For $W = 30$ kilotons, $w = 4.10^7$ lb., $R = 7{,}100$ ft., $P_m = 700$ p.s.i.
$P_r = (P_m + P_o)/P_c = 1.84$

Experimental evidence suggests that this value of P_r is likely to be too high for normally framed submarines of reasonably high yield stress. A value of $P_r = 1.4$ is more likely for a 20 kiloton weapon. Thus we have the surprising result that for a 30 K.T. weapon the Hogg formula gives a value for the lethal radius which is too small. Since the variation of lethal radius with charge weight is likely to change from a square root to a cube root law as the charge weight increases, the lethal radius value for 30 K.T. obtained by keeping to the square root law would be expected to be too large and not too small. The difficulty is illustrated in figure (1) where the relation $R = 1.13\ w^{\frac{1}{2}}$ is plotted on a log scale. The point obtained from the condition $P_r = 1.4$ for $w = 4.10^7$ is also plotted and it is clear that any curve passing through this point and tangenial to the Hogg formula curve for $w < 10^3$ needs to have a slope greater than $w^{\frac{1}{2}}$ in at least part of the intermediate region. Such a slop is unlikely to be correct and the inference is that the Hogg formula is in error. The modification leading to equation (6) makes things worse since it leads to smaller values of lethal radius.

An alternative and more recent lethal radius formula for conventional charges based on energy flux considerations is that due to Schauer (8). The original equation is expressed in terms of the American explosive HBX but it can be modified for T.N.T. into the following form

$$w^{1.0} = (21.2)R^{2.02}\ h\ \left(\frac{h^3}{d^2}\right)^{1/4} \sigma_y S \left[1 - \frac{P_o}{P_c}\right] \qquad (7)$$

where w, h, P_o, P_c are defined above

σ_y is the yield stress (10^3 p.s.i.)
d is the pressure hull diameter (ft.)
S is a frame strength parameter defined in figure (2).

The use of the Schauer formula for atomic weapons suffers from the objections discussed above. This is illustrated by the full line curve of figure (3) where the Schauer formula for the explosive HBX is plotted with $P_m/(P_c - P_o)$ as the ordinate and $F/(P_c - P_o)\theta^{5/4}$ as the abscissa, where

F is a factor depending on the detail design of the pressure hull
θ is the shock wave decay constant

The experimental results shown plotted are for charge weights much less than 1 K.T. full scale and the agreement with the Schauer formula is seen to be good. For the reasons discussed above the Schauer curve gives values for $P_m/(P_c - P_o)$ which are less than unity for large atomic weapons. For this reason the Schauer formula, and indeed the whole energy flux concept for predicting lethal radii, is rejected in reference (9). However, the simple remedy of considering only the energy flux up to the instant when the shock wave pressure equals the collapse pressure $P_c - P_o$ overcomes this difficulty. The modified equation is

$$w^{1.09} \left\{1 - \left(\frac{P_c - P_o}{P_m}\right)^2\right\} = (21.2)R^{2.02}\ h\ \left(\frac{h^3}{d^2}\right)^{1/4} \sigma_y\ S\left(1 - \frac{P_o}{P_c}\right) \qquad (8)$$

/and

and this equation gives the dotted curve of figure (3). The experimental results agree as well with the dotted curve as with the full curve and the dotted curve asymptotes to the desired value $P_m/(P_c - P_o) = 1$ as $\theta \to \infty$.

For the numerical example of figure (4), the lethal radius for a 30 K.T. (Radio Chemical Yield) explosion ($w = 4.10^7$) given by equation (8) is 8400 ft. giving a value for $P_r = (P_m + P_o)/P_c = 1.61$. This value for P_r is still somewhat higher than might be expected (see above) and for other submarine designs, the values of P_r for a 30 K.T. charge against the submarine at 500 ft. submergence can rise as high as 2. This suggests (but by no means proves) the inadequacy of the modified Schauer formula.

To overcome this difficulty about the value of P_r obtained for 30 K.T. charges it is possible to use the following more general lethal radius equation based on energy flux ideas.

$$w\left\{1 - \left(\frac{P_c - P_o}{P_m}\right)^2\right\} = AR^2\left\{1 - \left(\frac{P_o}{P_c}\right)^\gamma\right\} \qquad (9)$$

where A is a constant to be determined. If it is stipulated that $(P_m + P_o)/P_c = P_r$ when $w = w_1$ and $P_o = \beta P_c$, A becomes

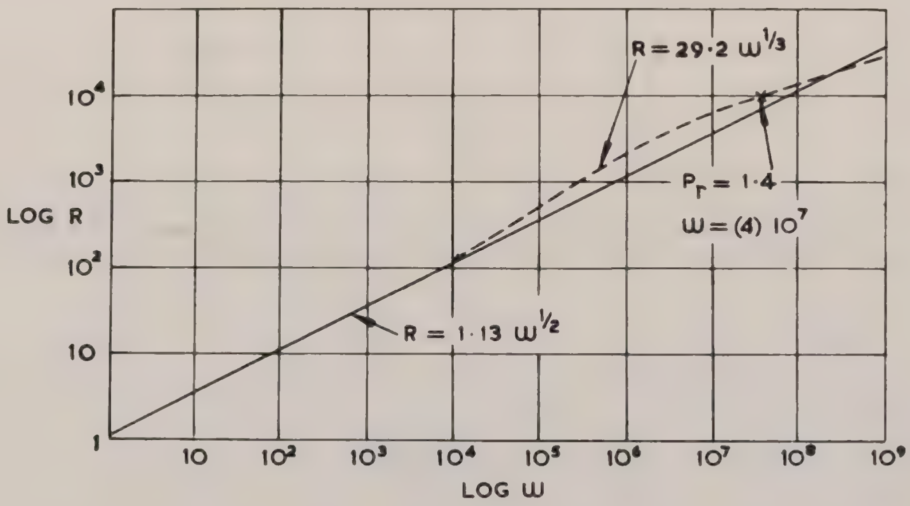
$$A = w_1^{\;1/3}\left\{1 - \frac{(1-\beta)^2}{(P_r - \beta)^2}\right\}\left\{\frac{P_r - \beta)P_c}{21,600}\right\}^{1.77}/(1 - \beta^\gamma) \qquad (10)$$

if $P_m = 21,600\,(w^{1/3}/R)^{1.13}$. For the particular case of interest when $w_1 = 4.10^7$,

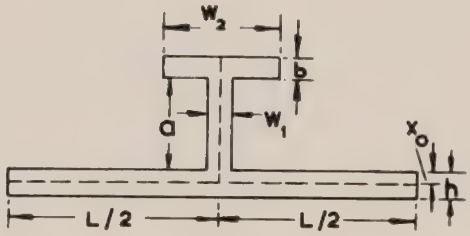
$\gamma = 1$, $\beta = 0.5$, $P_r = 1.4$

$$A = (83.6)10^{-7}\ P_c^{\;1.77} \qquad (11)$$

The constant A of equation (10) can be chosen to give any desired lethal radius for a particular set of values w, P_c, P_o. The value of this is that only one experimental result is required to enable lethal radii predictions for different charge weights and depths of submergence to be carried out. The particular value for A given in equation (11) is based on the experimental evidence available to date, namely, that for a 30 K.T. charge a value $P_r = 1.4$ is about right for a deeply submerged submarine.



RELATIONSHIP BETWEEN LETHAL RADIUS AND CHARGE WEIGHT



$$\left[h - x_o\right] L = x_o L + a W_1 + b W_2$$

$$S = \frac{L\left\{\left[h - x_o\right]^2 + x_o^2\right\} + W_1\left\{\left[a + x_o\right]^2 - x_o^2\right\} + W_2\left\{\left[a + x_o + b\right]^2 - \left[a + x_o\right]^2\right\}}{2\,hLd}$$

$$= \frac{M_o}{\sigma_y\, hLd}$$

M_o = PLASTIC MOMENT OF STIFFENER AND ONE FRAME SPACING OF HULL PLATING.

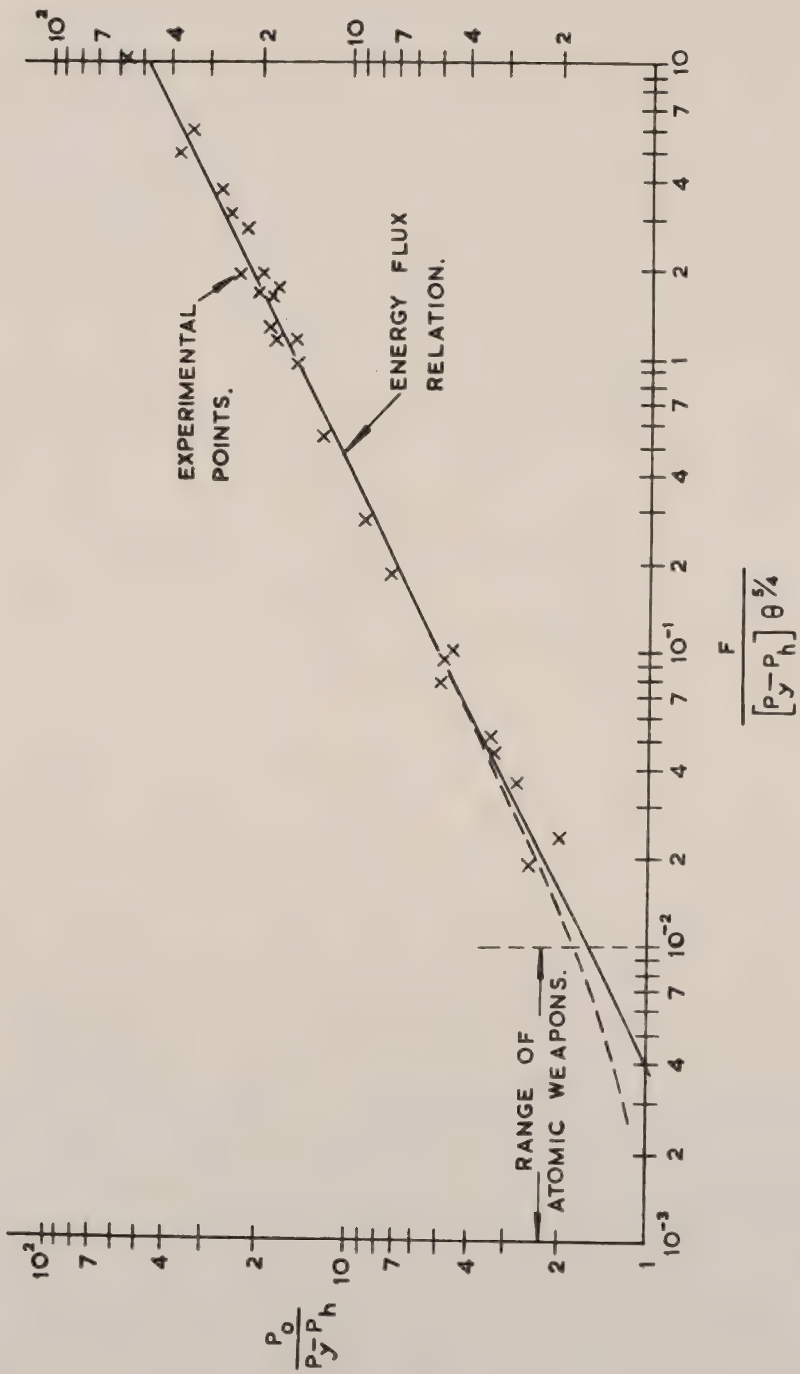
h = HULL THICKNESS. [IN.]

L = FRAME SPACING. [IN.]

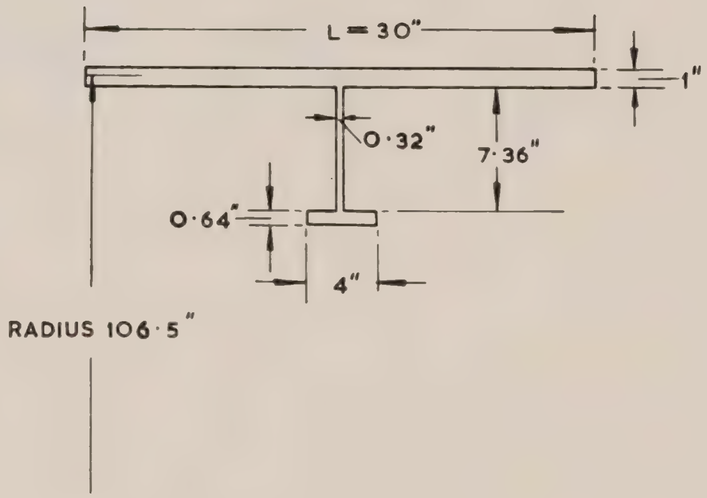
d = HULL DIAMETER. [IN.]

σ_y = YIELD STRESS.

DEFINITION OF FRAME STRENGTH PARAMETER [S]



SCHAUER LETHAL RADIUS
FORMULA FOR HBX



YIELD STRESS 27 TONS / IN²

DEPTH OF SUBMERGENCE 500 FT. $[P_o = 222]$

COLLAPSE PRESSURE $P_c = 500$ P.S.I.

NUMERICAL EXAMPLE OF MODIFIED SCHAUER FORMULA

4.6 The Excess Impulse Criterion

Perhaps the most plausible lethality criterion yet proposed is that based on excess impulse which considers that lethality is associated with a given value of the parameter

$$I_e = \int_0^{t_1} (P_i + P_o - P_c)dt \qquad (12)$$

where P_i is the incident shock wave overpressure
t_1 is the time at which $P_i = P_c - P_o$

When $P_i = P_m e^{-t/\theta}$ the excess impulse neglecting surface cut off becomes

$$I_e = (P_m \theta) - [(P_c - P_o)\theta] \; [1 + \log_e \{P_m/(P_c - P_o)\}] \qquad (13)$$

The critical excess impulse will vary for each class of submarine but Keil (9) suggests that

$$(I_e)_{\text{critical}} = 2.13 \text{ h p.s.i. - secs.} \qquad (14)$$

where h is the plating thickness in inches.

It will not be demonstrated that under certain simplifying assumptions the maximum uniform radial displacement of a circular cylinder is proportional to the excess impulse: Under attack of lethal or near lethal severity, the response of a pressure hull becomes inelastic at fairly small times when the mean radial displacement is small compared to the plating thickness. Assuming that, beyond the elastic limit, plane wave damping applies, inertia effects are insignificant and the yield stress is dynamically enhanced so that

$$\sigma = \sigma_y + K \dot{w}_o/a \qquad (15)$$

the differential equation of motion may be written

$$\left(\frac{h}{a}\right) \; [\sigma_y + K \dot{w}_o/a] \;\; + \rho c \dot{w}_o = P_i + P_o \qquad (16)$$

$$\text{i.e. } \dot{w}_o = (P_i + P_o - P_y)/(\rho c + hK/a^2) \qquad (16)$$

where $P_y = h\sigma_y/a \simeq P_c$. Integrating equation (15) gives

$$w_{op} = \frac{1}{[\rho c + (hK/a^2)]} \int_0^{t_1} (P_i + P_o - P_c)dt \qquad (17)$$

where w_{op} is the maximum plastic deformation

t_1 is the time at which $P_i + P_o = P_c$

$$\text{i.e. } w_{op} = I_E/[\rho c + (hK/a^2)] \qquad (18)$$

Taking the critical value I_e given in equation (14) leads to the following expression for the critical value of w_{op}

$$(w_{op})_{max} = \frac{(0.37)h}{1 + (0.173)hK/a^2} \qquad (19)$$

Thus according to this simplified theory $(w_{op})_{max}$ cannot exceed 37% of the plating thickness if collapse is to be avoided. This critical value for the mean radial displacement may seem surprisingly low but the mean displacement possibly serves as a trigger for bending distortions of the framing which would soon lead to much larger deflections. The assumption of plane wave hydrodynamic damping also reduces the mean deflection value obtained since the afterflow term in the hydrodynamic equation (16) has the effect of reducing the relief pressure.

4.7 The Effect of Surface Cut-Off

The discussion of lethality criteria for submarines has so far been confined to attack geometries such that

either (1) the curve of average stress versus T (see Section 4.3) touches the delayed yield stress curve.
(2) the critical excess energy value is reached
(3) the critical excess impulse value is reached

before the arrival of the surface cut-off which effectively reduces the incident pressure to zero. In very many cases of interest, however, this will not be the case and it is necessary to examine the effect of cut-off on lethal radii.

It is possible to carry out the calculation for the delayed yield criterion, described in Section 4.3, allowing for cut-off by taking the incident pressure as

$$P_i = P_m e^{-t/\theta} \text{ for } t \leqslant \tau$$

$$P_i = 0 \text{ for } t > \tau$$

where τ is the cut-off time. The linearity of the problem makes this simply a matter of adding the solutions obtained to the following problems

Case (a) $P_i = P_m e^{-t/\theta} \quad 0 \leqslant t \leqslant \infty$

Case (b) $P_i = 0$ for $0 \leqslant t \leqslant \tau$ $P_i = P_m e^{-\tau/\theta} e^{-t'/\theta}$ for $t = t' + \tau > \tau$

The solution to case (b) is clearly the same as for case (a) times a factor $-P_m e^{-\tau/\theta}$ and with change of time origin. Using this approach the effect of cut-off on the response shown in figure (2) Section 4.2 has been calculated and is shown in figure (1) for varying values of the cut-off parameter $c\tau/a$. The increase in deflection after cut-off occurs is of particular interest. This increase is very small for cut-offs as late as 1.5 times the transit time 2a/c rising to about 20% for small cut-off times. The increase in deflection after cut-off is due to inertia effects and since the inertia of the shell plating is too small to account for an increase of as much as 20%, the effect must be principally due to the effective additional inertia of the water. Put another way, the motion of the cylinder radially inwards involves a radially inwards movement of water. The arrival of the plane wave associated with cut-off can have no direct effect on this radial movement of water which has to be slowed down and stopped by the elastic resistance of the cylinder.

To allow for the effect of cut-off on the excess energy and excess impulse criteria it is necessary to evaluate both the cut-off time

$$\tau = (R/c) \left\{1 + \left(\frac{4dD}{R^2}\right)\right\}^{\frac{1}{2}} - (R/c) \tag{20}$$

and the time

$$t_1 = (\theta) \log_n \left(\frac{P_m}{P_c - P_o}\right) \tag{21}$$

where R is the slant radius
d is the depth of submergence of the submarine
D is the charge depth
c is the velocity of sound in water
θ, P_m, P_c and P_o have been defined previously.

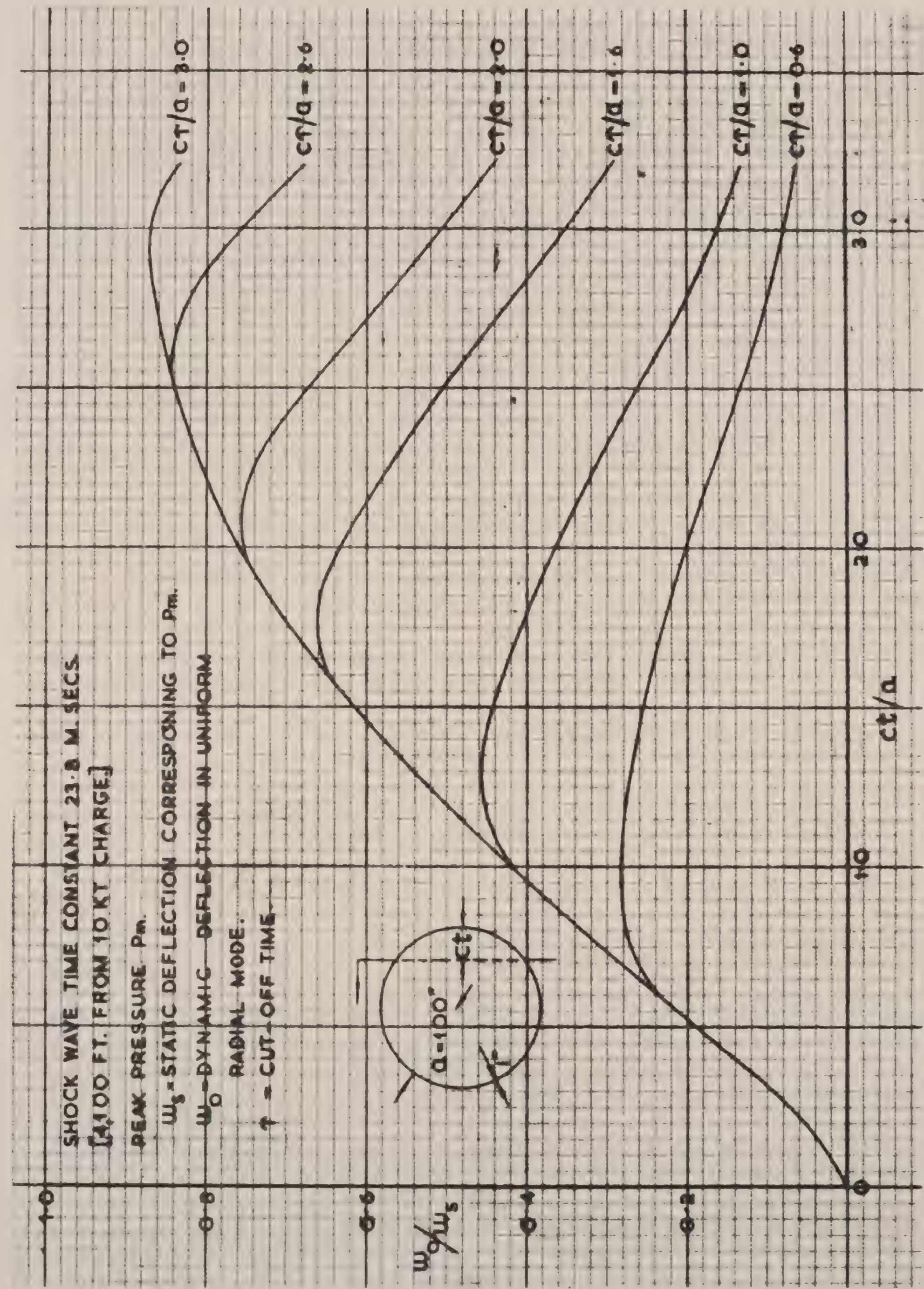
If $\tau > t_1$, cut-off has no effect and equations (9), (13) still hold. If $\tau < t_1$, cut-off has the effect of reducing the lethal radius and the following equations hold.

For excess energy

$$w\left\{1 - e^{-2n\tau}\right\} = AR^2 \left\{1 - \left(\frac{P_o}{P_c}\right)^{\alpha}\right\} \tag{22}$$

For excess impulse

$$I_E = P_m\,\theta\left\{1 - e^{-n\tau}\right\} - (P_c - P_o)\tau = (2.13)h \tag{23}$$



THE EFFECT OF SURFACE CUT - OFF ON ELASTIC RESPONSE IN THE RADIAL MODE

4.8 Comparison of Excess Impulse and Energy Criteria

It is of interest to see how the lethal radii values obtained using the "Excess Impulse" and the "Excess Energy" criteria compare numerically. For this purpose several examples of interest have been calculated and are shown in the following Table (1).

TABLE I

Lethal Radii in the Absence of Refraction, Cavitation, etc.

Weapon Yield W	Collapse Pressure (p.s.i.)	Excess Impulse (p.s.i. sec.)	Charge Depth (feet)	Submarine Depth (feet)	Lethal Radii (ft.)	
					Excess Impulse	Excess Energy
1.5	500	2.13	500	50	1810	1525
"	"	"	"	500	2670	2480
"	"	"	2000	50	1920	1820
"	"	"	"	500	2670	2480
30	"	"	500	50	3900	3610
"	"	"	"	500	8970	8220
"	"	"	2000	50	4900	5390
"	"	"	"	500	9740	9840
3000	"	"	500	50	15800	17900
"	"	"	"	500	43700	44500
"	"	"	2000	50	25800	27700
"	"	"	"	500	73500	67700
30	670	3.1	500	50	3190	3050
"	"	"	"	500	6330	6420
"	"	"	2000	50	4610	4500
"	"	"	"	500	6410	6740

The agreement between the lethal radii obtained from the two criteria is seen to be good (within 7% on average) in fact so good that experimental work could not be expected to provide a valid choice between the two criteria. The "Excess Energy" criterion is slightly the easier to compute and should give reasonably correct answers for lethal radius for most cases of interst apart from those in which refraction plays a large Part. (See Section 4.10).

Part V
Chapter 4
Section 4.9

D1/57
January, 1959

4.9 The Effect of Cavitation

The lethal radii values given in Table (1) Section (4.8) show marked reductions for shallow submergence of submarine and bomb. These reductions are due to the effect of surface cut-off which reduces the shock wave pressure to near zero whilst increasing the vertical particle velocity and decreasing the horizontal particle velocity. The possible damaging power of the increase in vertically directed kinetic energy has been neglected, perhaps unjustifiably.

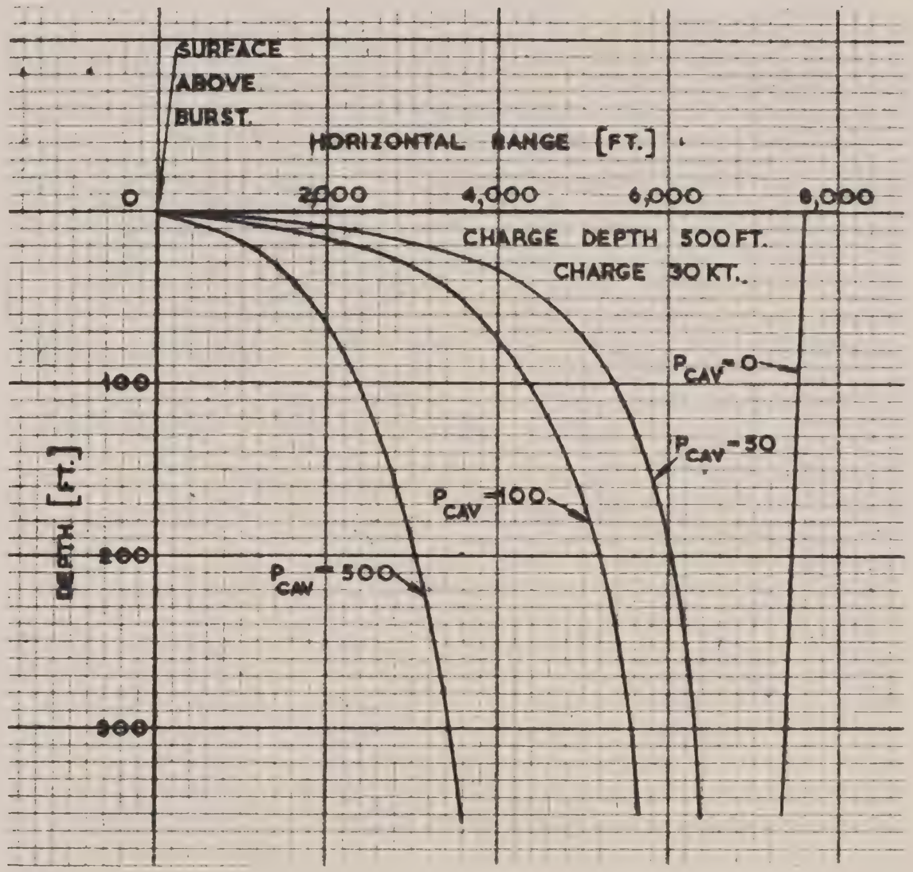
If sea water could withstand tension, the sea surface would reflect all the shock wave energy as a tension wave. However due to the finite and probably very small tensile strength of sea water cavitation will usually occur and considerably modify this process. Curves showing the positions at which tensions of various magnitudes are first reached (cavitation inception surfaces) are shown in figures (1) - (4) for several cases of interest. The actual cavitation tension of sea water is probably less than 50 p.s.i. for shock waves from atomic explosions. The water above a cavitation inception surface can be expected to separate from the sea beneath. This water can be considered as a solid water layer with atmospheric pressure above and vapour pressure below and it very soon falls back towards the main bulk of water. The closure of the gap results in a pulse generated in a water hammer manner.

Experimental measurements of this surface reloading pulse have been taken and a typical record is shown in figure (5). Sound ranging on the pulses have shown them to originate near the sea surface and their time of occurrence agrees reasonably well with theoretical expectations of the motion of the water above the cavitation gap. The phenomenon may be expected to be complicated by the reflection of the remainder of the shock waves at the first cavitation gap causing a second cavitation gap and so on.

It is clear that the finite breaking tension of sea water can have the effect of converting some of the reflected tension wave into a reflected compression wave. This compression wave may be capable of damaging submerged submarines and this may counteract to some extent the benefit of shallow submergence to be expected purely on cut-off considerations.

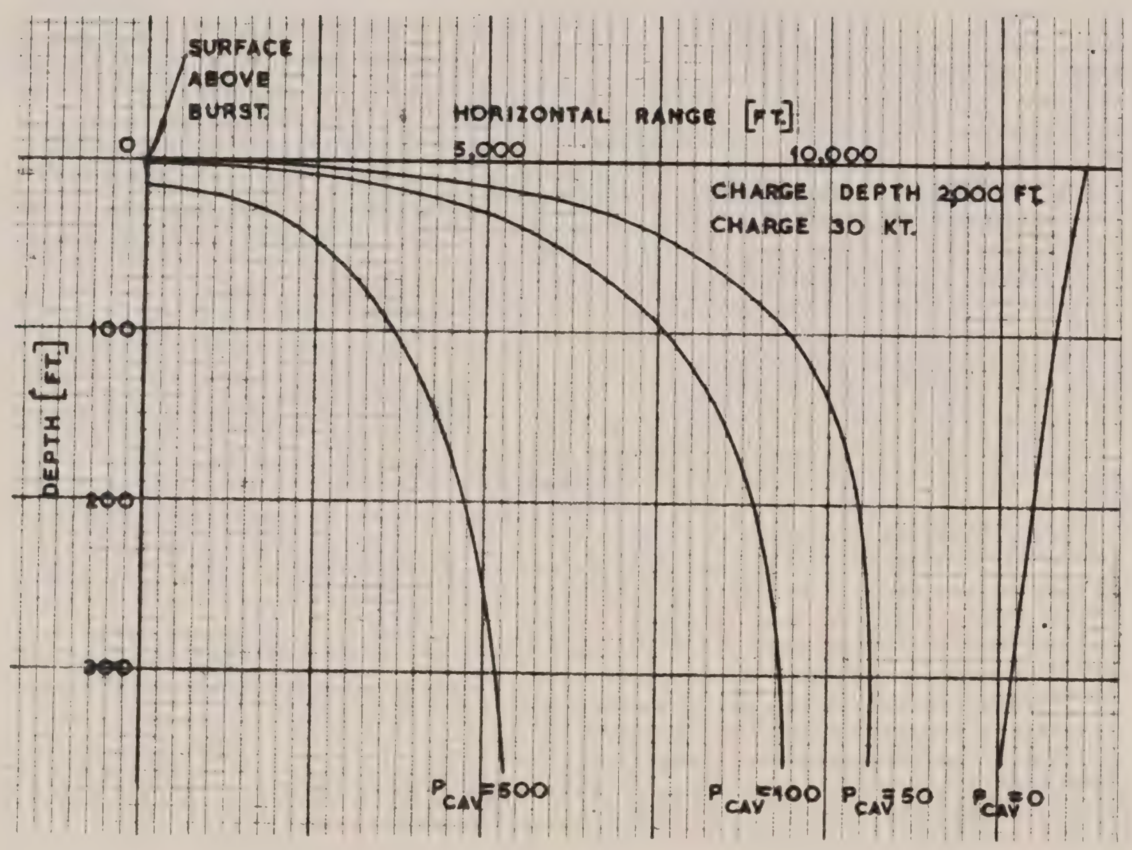
Rather little is known about surface reloading pulses, but the present consensus of opinion seems to be that they are unlikely to be serious damaging agents for submerged submarines. Doubts about the scaling laws for surface reloading phenomena make the interpretation of small scale experiments difficult at present.

For References see end of chapter.



CAVITATION SURFACES

CONFIDENTIAL



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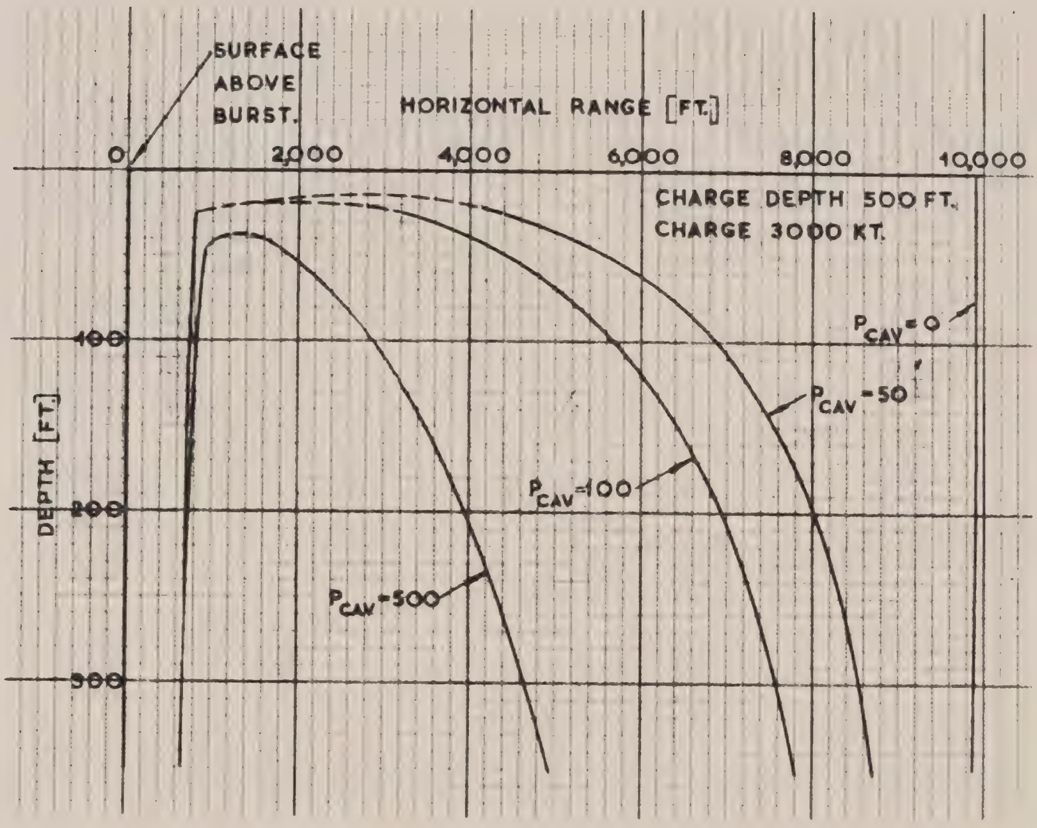
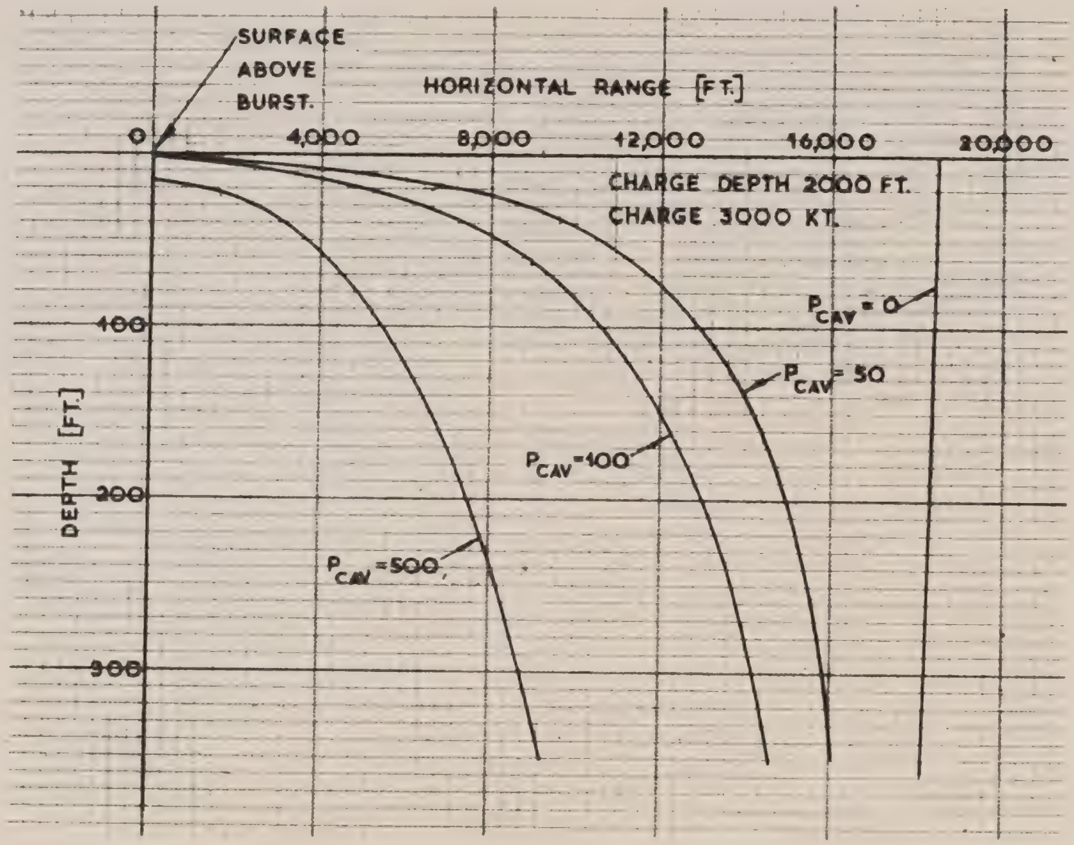
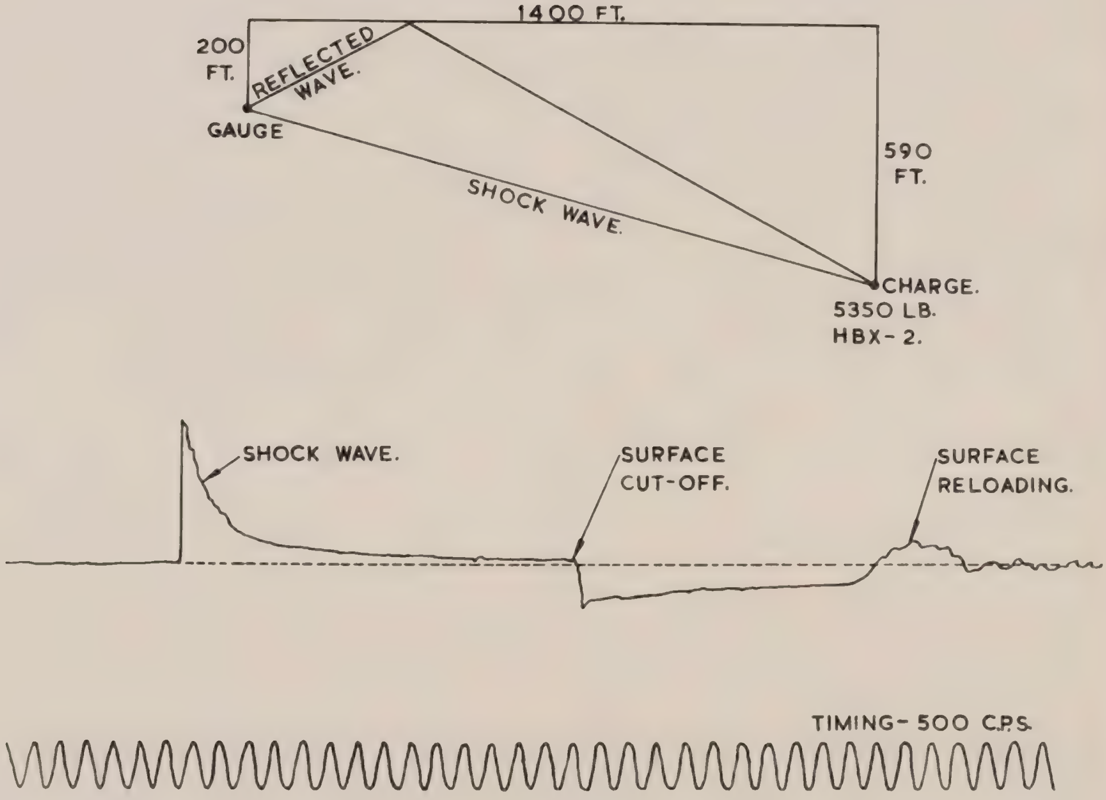


CAVITATION SURFACES

CONFIDENTIAL



CAVITATION SURFACES



MEASUREMENT OF SURFACE
RELOADING PULSE

4.10 The Effect of Refraction

The values for lethal radius for megaton weapons given in Table (1) Section 4.8 show that the variation of lethal radii with charge weights for a given burst depth is appreciably less than $W^{\frac{1}{3}}$. This is due to the effect of surface cut-off. If the charge depth could be increased as $W^{\frac{1}{3}}$ the lethal ranges would then increase nearly as $W^{\frac{1}{3}}$ on going from kiloton to megaton weapons but this would involve very large charge depths.

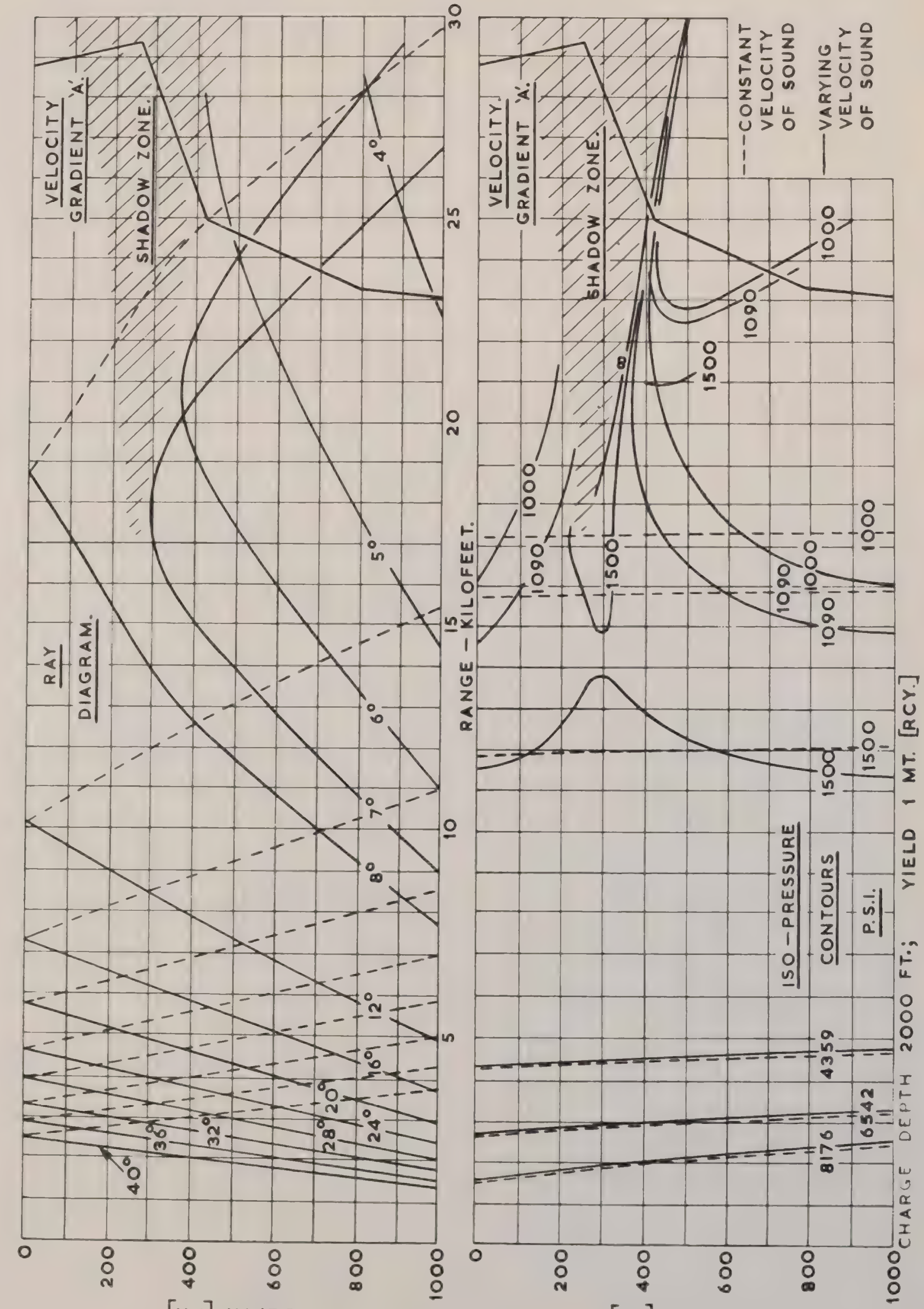
In spite of this effect of cut-off, the lethal radii for megaton weapons are very large, in fact so large that a phenomenon not so far considered can be expected to play a dominating role. This is the phenomenon of refraction due to the non-uniformity of the temperature and salinity of the sea.

In many areas of the oceans the temperature and salinity vary with depth sufficiently to cause changes in the velocity of sound of 1 or 2 per cent over a depth of 2000 ft. The shock front of an explosion wave can be considered to propagate, at the local velocity of sound, along rays which in isovelocity water spread out radially from the explosion source, but which get bent in a medium of varying sound velocity. The rays always take the path shortest in time between any two points, so that when the velocity of sound decreases with depth the rays are bent downwards, and vice versa. This bending of the rays affects the intensity of the shock front; diverging rays reducing the intensity, converging rays increasing the intensity. Thus regions could exist where no rays penetrated. These regions are called shadow zones, and on ray theory they are zones of zero shock wave pressure. In fact, however, the tail of the shock wave does not propagate strictly according to ray theory, and some diffraction of the shock wave into the shadow zone always occurs.

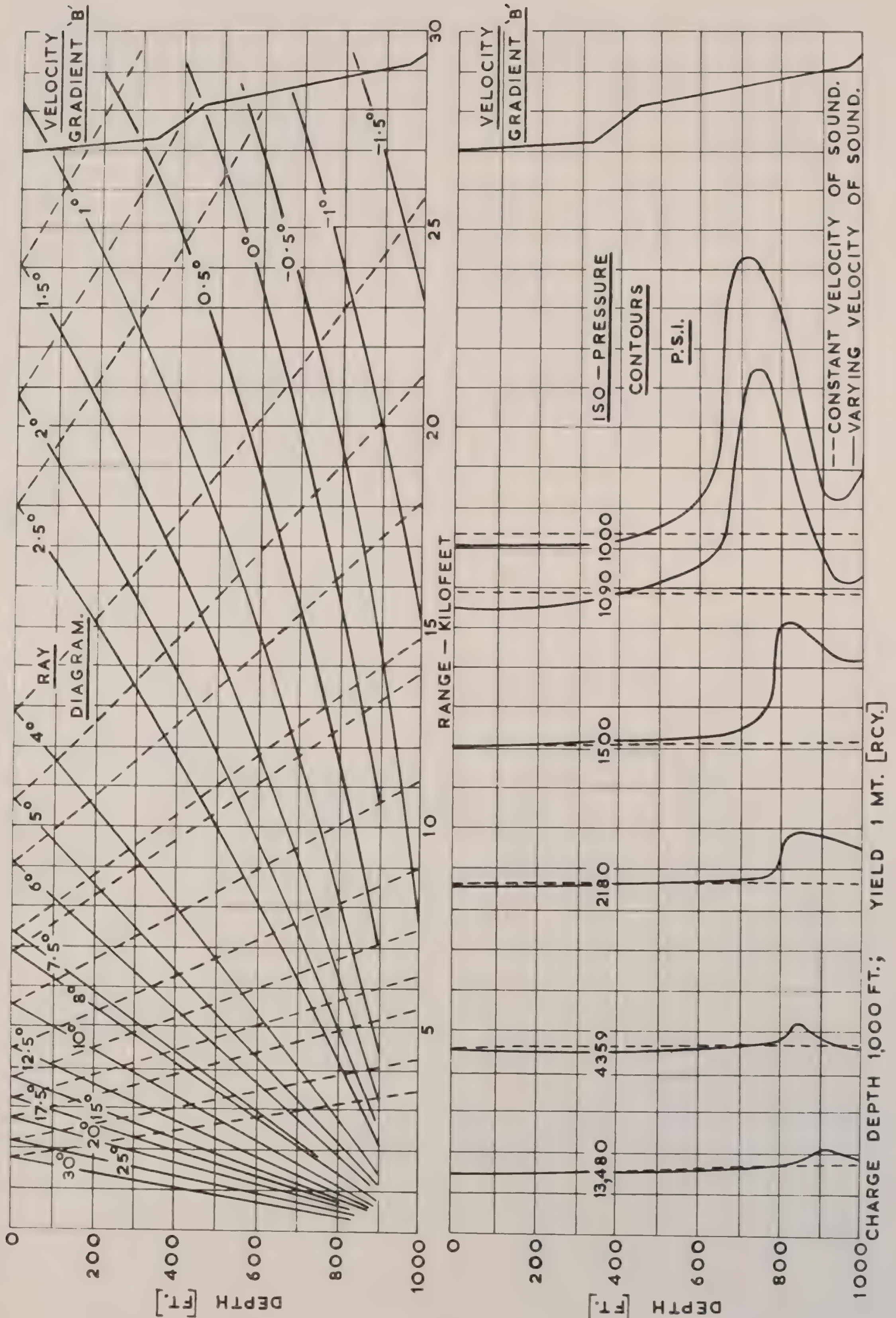
The refraction effect is, to the accuracy of ray theory, purely a function of range and not of charge weight. For conventional H.E. charges the ranges of interest are too small for any significant refraction to take place. For atomic explosions up to 20 KT the effect of refraction is not expected to have a great influence on lethal radii except in special cases. For megaton weapons, however, the ranges of interest are such that refraction effects can be expected to predominate, and the results of Table (1) Section 4.8 are unlikely to hold except as very rough average values that can be far out in specific cases.

To illustrate this fact, the results of ray calculations for March and November near Bermuda are shown in figures (1), and (2). The ray diagrams (taken from Reference 11) show the degree of ray bending that occurs for two particular velocity gradients and depths of burst, as specified in figure 3. These ray diagrams are independent of charge weight. Of more direct interest are the contours of constant shock wave peak overpressure for 1 megaton of T.N.T. These contours can be seen to differ appreciably from the isovelocity contours (circles).

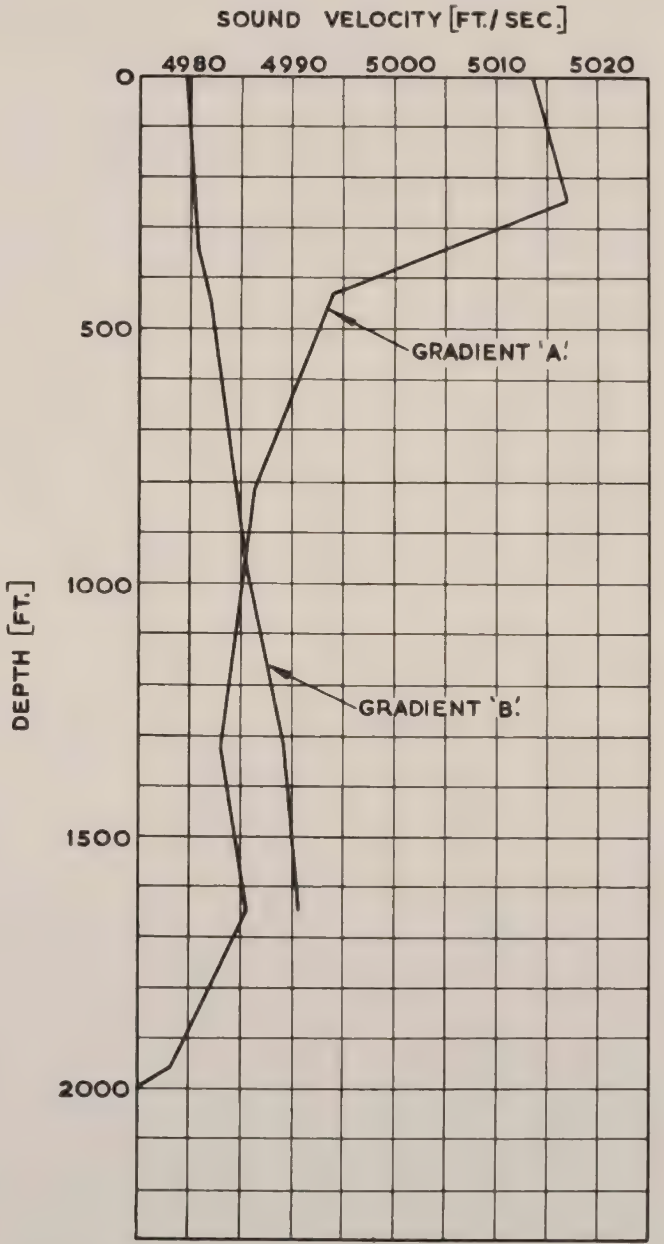
Ray theory is fairly simple to compute, but it can give no indication of pressure time histories. To improve on ray theory sufficiently to enable pressure time histories to be calculated appears to be very difficult, and much theoretical and experimental work will be necessary before this is possible. For this reason calculation of lethal radii under refractive conditions is not at present possible. When the pressure pulse is known, however, all three lethality criteria discussed above - delayed yield, excess energy and excess impulse can be adapted to assess the likely damage. Experimental work on the refraction of underwater shock waves is being carried out at N.C.R.E. Some references are given at the end of this chapter.



REFRACTION OF UNDERWATER SHOCK WAVE,
1 MT BURST AT 2,000 FT. DEPTH.



REFRACTION OF UNDERWATER SHOCK WAVE,
1 MT BURST AT 1,000 FT. DEPTH

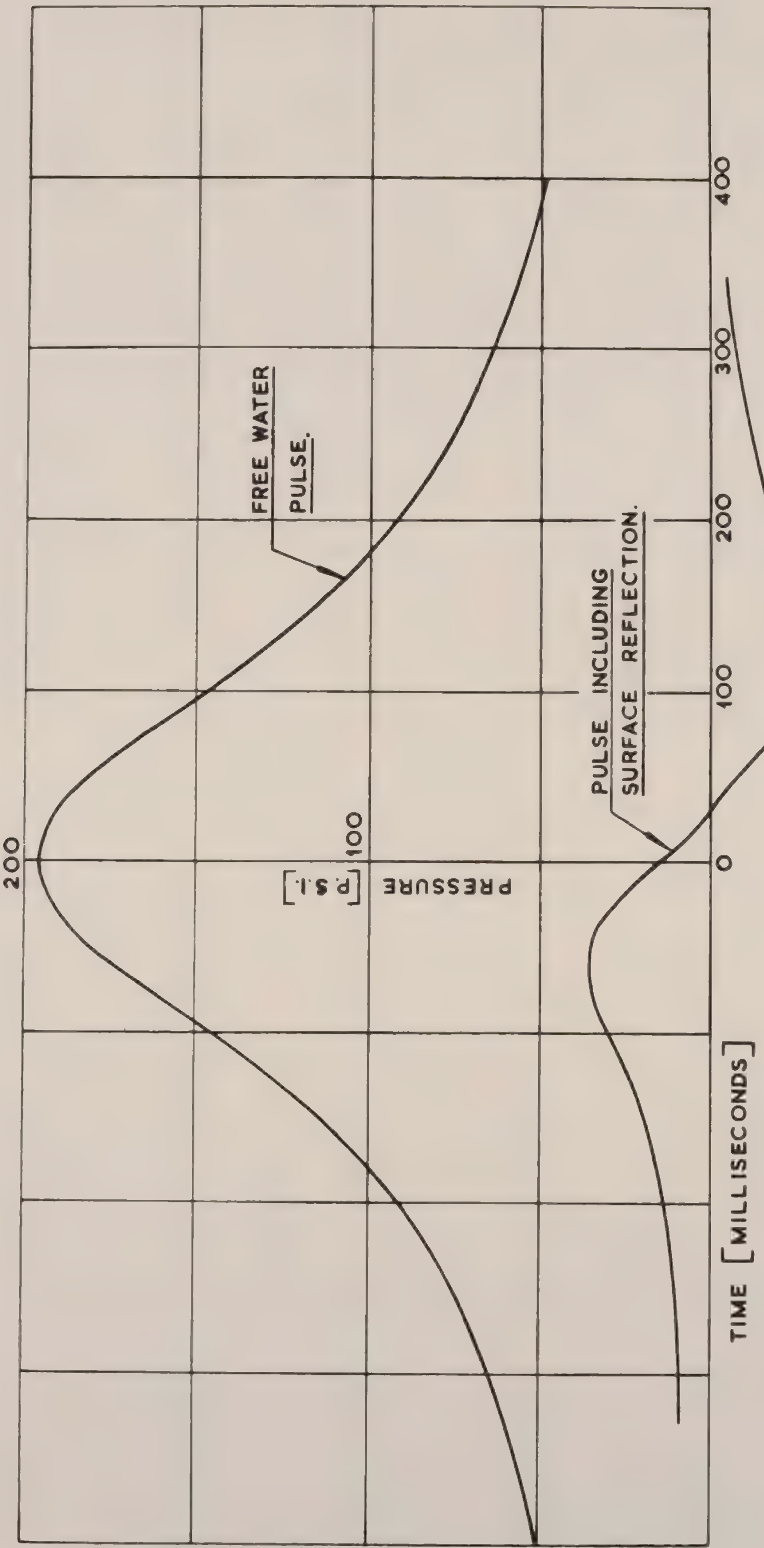


VARIATION OF SOUND VELOCITY
WITH DEPTH

4.11 The Effect of Bubble Pulses

When conventional high explosive depth charges are used to attack submarines the lethal stand-off is usually of the order of 20 ft. at which distance the peak shock wave pressure is 5000 p.s.i. or more. The bubble pulse pressures are likely to be only about 1/10th of this value but the duration is longer than that of the shock wave and 500 p.s.i. is capable of damaging most submarines. Thus the bubble pulse can and usually does cause damage for high explosive attack.

The position is quite different for atomic weapon attack since the peak shock wave pressures at lethal stand-off's are unlikely to exceed 2000 p.s.i. The bubble pulse peak pressure in free water cannot exceed 1/7th of this value, i.e. 300 p.s.i. and this pressure could scarcely damage a modern submarine even if reflection from the free surface was absent. In fact, however, the effect of surface reflection will always be to reduce the peak bubble pressure for free water to much smaller values. This is illustrated in figure (1) where the first bubble pulse, in free water, 3000 ft. from a 23 KT charge exploded 2000 ft. deep is given. Also given is the pulse experienced at 500 ft. submergence when surface reflection is taken into account. The latter pulse is obviously too feeble to have any significance. This conclusion remains generally valid for all larger weapons. If a submarine were almost directly over a very deep explosion, vertical migration could conceivably bring the pulsating bubble near enough to do damage. This would be a strange way to attack a submarine. In the case of surface ships the nearness of the pulsating bubble would almost certainly imply a greater danger from radiation when the bubble breaks surface than from the actual bubble pulse.



FREEWATER BUBBLE PULSE, 3,000 FT. FROM 23 KT
EXPLODED AT 2,000 FT. DEPTH

4.12 Shock Damage to Submarines

The problem of shock to machinery etc. is likely to depend considerably upon the orientation of the attack. For end-on attack and ranges greater than the hull splitting range, little shock damage is likely. For side-on attack two effects are likely to predominate -

(a) Local hull motions along the generator line nearest to the point of explosion

(b) Rigid body motion of the entire submarine cross section.

There is little doubt that the shock problem will usually be less with atomic weapons than with conventional high explosive weapons. This is because the peak pressures at the hull splitting stand-offs are always less for atomic weapons. Thus if, as is attempted, all submarine equipment were successfully designed to resist the shock at hull splitting stand offs for high explosive weapons, there would be no shock problem for atomic weapons. In fact, however, it is unlikely that any submarine designed to date achieves this ideal, and shock is likely to be a significant problem under attack by atomic weapons, although possibly only for shallow submarines.

(a) Local Hull Motions

Points facing the explosion can be expected to acquire velocities close to $2P_m/\rho c$ (see Section 3.5). This velocity has been evaluated for the cases given in Table (I), Section (4.8) and the results are given in Table I below -

TABLE I

Yield W (kilotons)	Collapse Pressure (p.s.i.)	Charge Depth (feet)	Submarine Depth (feet)	Slant Range (Hull Splitting) (ft.)	Peak Pressure (p.s.i.)	$\frac{2P_m}{\rho c}$ (ft./sec.)
1.5 KT	500	500	50	1810	1063	30.6
"	"	"	500	2670	685	19.7
"	"	2000	50	1920	990	28.4
"	"	"	500	2670	685	19.7
30 KT	"	500	50	3900	1380	39.6
"	"	"	500	8970	538	15.5
"	"	2000	50	4900	1070	30.7
"	"	"	500	9740	491	14.1
30,000 KT	"	500	50	15800	3832	110
"	"	"	500	43700	1210	35
"	"	2000	50	25800	2210	63.5
"	"	"	500	73500	67.5	19.4
30 KT	670	500	50	3190	1730	49.1
"	"	"	500	6330	792	22.8
"	"	2000	50	4610	1138	32.6
"	"	"	500	6410	785	22.5

There is a considerable doubt about the value of local hull velocity required to cause serious shock damage. This is rather inevitable since the answer depends upon the degree of "shock-consciousness" of the designers of the equipment. Ideally a submarine should be capable of withstanding plating velocities of about 60 ft./sec. In fact a value of about 35 ft./sec. for plating velocity is likely to lead to serious damage in most submarines.

(b) Rigid Body Motion

The motions of the entire submarine cross section can be calculated to a first approximation as the response of a circular cylinder of neutral buoyancy. This response is only a function of the parameter $\beta a/c$ where $(1/\beta)$ is the time constant of the shock wave $\left(P = P_m e^{-\beta t}\right)$

a is the radius of the cylinder
c is the velocity of sound

Figure (1) gives the response for a wide range of the parameter $\beta a/c$.

For any particular attack geometry $\beta a/c$, $P_m/\rho c$ and a/c are known and multiplying the appropriate curve (or an interpolated curve) of figure (1) by $(P_m/\rho c)$ for the ordinate and a/c for the abscissa gives the resultant rigid body velocity in free water in the direction of propagation of the shock wave. The effect of cut-off can easily be obtained by superposition, as follows:-

> First plot the vertical and horizontal components of the resultant rigid body velocity in free water. These are just $\sin\alpha$ and $\cos\alpha$ times the resultant velocity respectively (figure 2). Then plot on the same graphs the vertical and horizontal components of the resultant velocity obtained from the image charge delayed by a time equal to the cut-off time. The sum of the velocity produced by the charge and the image charge give the velocity histories under the influence of cut-off. For a typical set of velocity curves see figures (2) and (3).

Experimental measurements of bodily velocities tend to give appreciably higher values than those calculated for a neutrally buoyant rigid cylinder. This is possible because the outer hull weight of submarine is only a fairly small percentage of the total weight. Thus the outer hull, which responds before the machinery etc. inside can do so, can acquire bodily velocities higher than the average. This means that vibrations can be set up with momentary velocity of individual items appreciably greater than the average. The maximum velocity that can be achieved in this way is twice that for a neutrally buoyant rigid cylinder.

A typical bulkhead velocity recording taken from reference 10 is shown in figure (4), where the theoretical curve is included for comparison. The experimental maximum velocity is seen to be about 75% greater than the theoretical.

In spite of this increase of experimental over theoretical rigid body velocities, the maximum rigid body velocity will always be less than, or just possibly equal to, the local hull velocity treated in (a) above. This does not necessarily mean, however, that the shock problem due to local hull velocity will always be the greater, since many an item in a submarine can be expected to be more sensitive to say 15 ft./sec. applied directly to itself, than to say 30 ft./sec. applied at the hull - leading to considerably less at the item. There is even a possibility that the large horizontal bodily velocities that can be experienced under atomic attack constitute a new shock problem that is not important for conventional attack.

Probably the best guess that can be made at present is that 10 ft/sec. horizontal and 20 ft/sec. vertical bodily velocities, give about the limit of serious shock damage. Bearing in mind the increase of experimental over theoretical values this suggests theoretical limiting values of about 8 and 15ft./sec. for horizontal and vertical velocities respectively.

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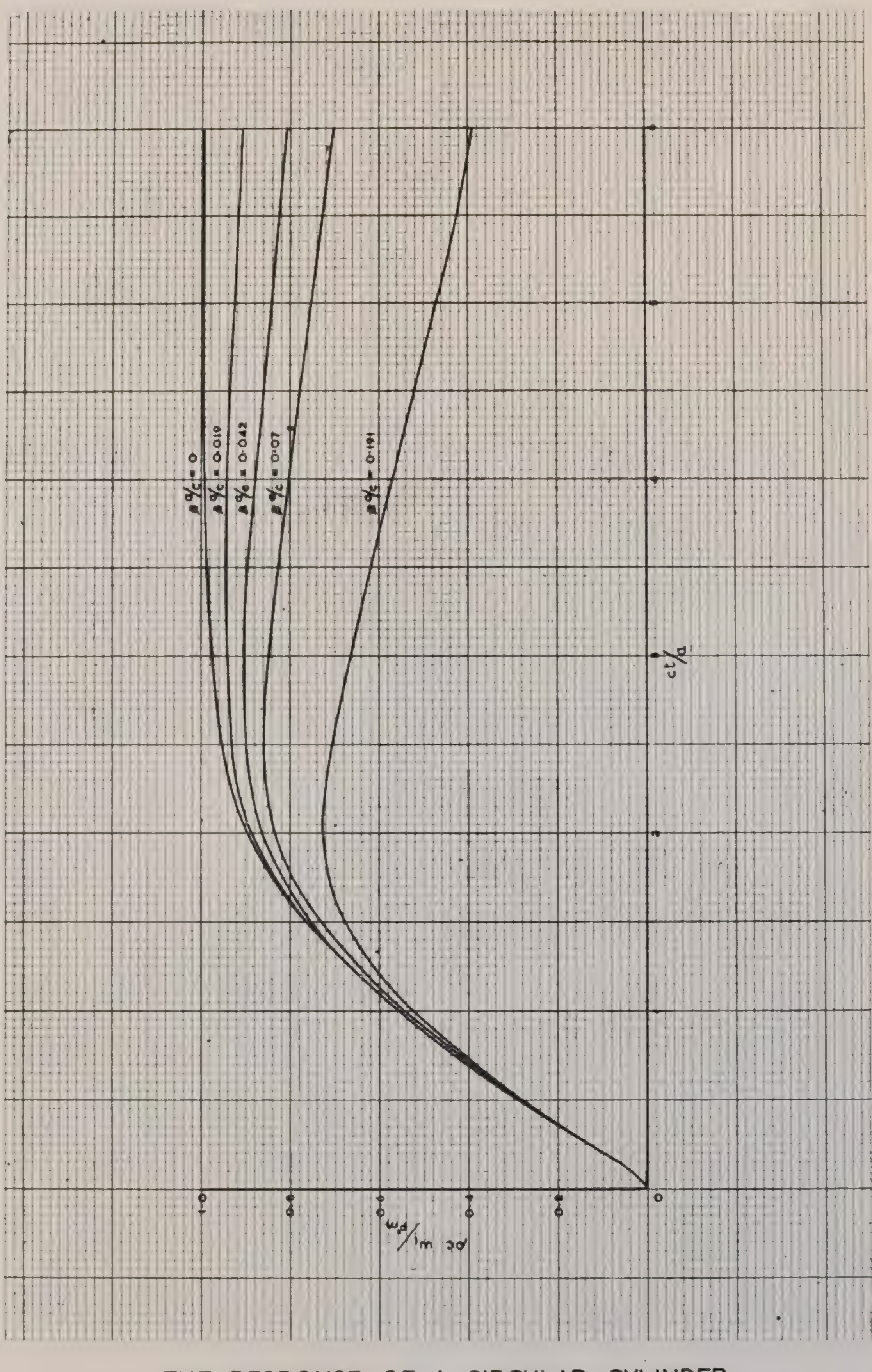
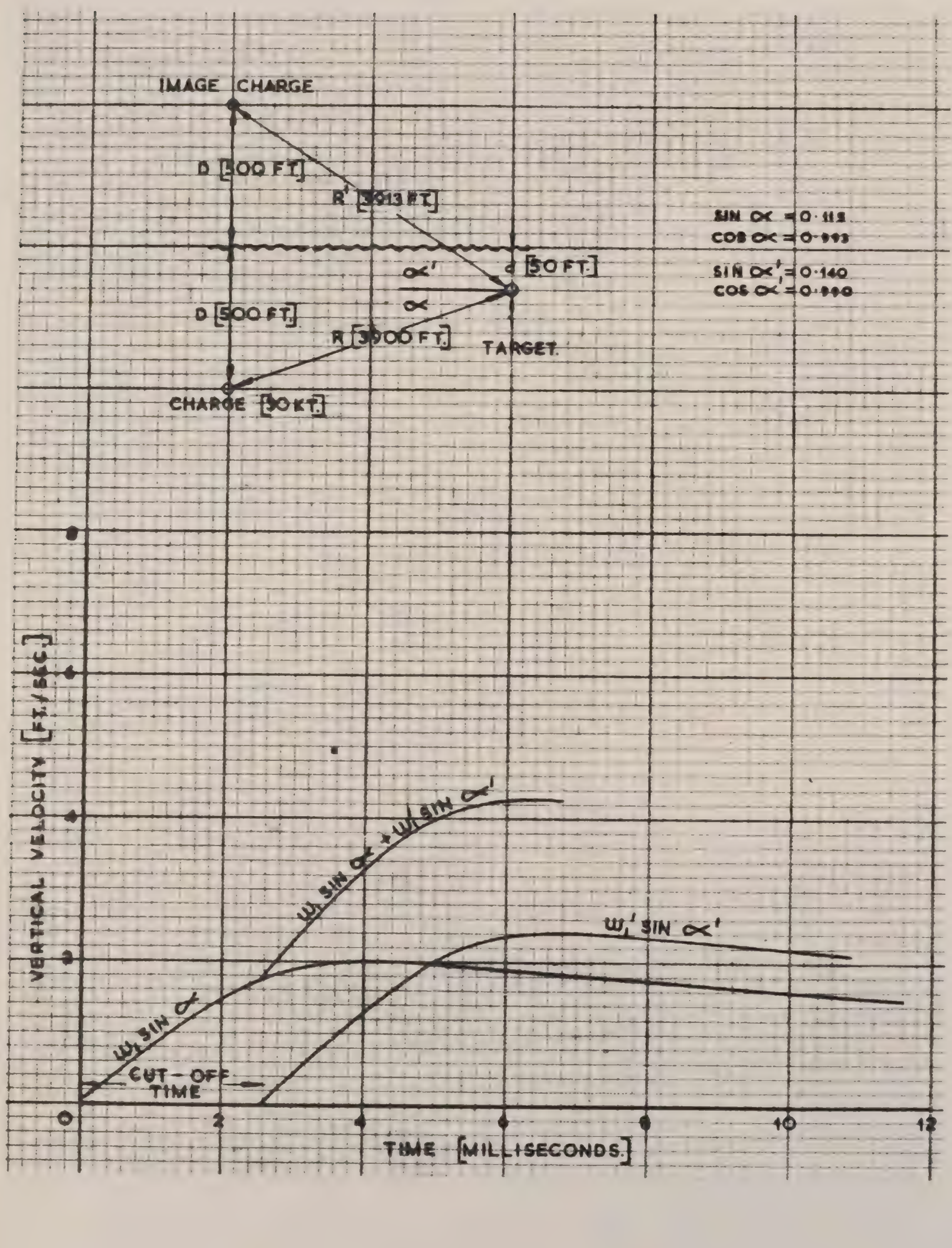
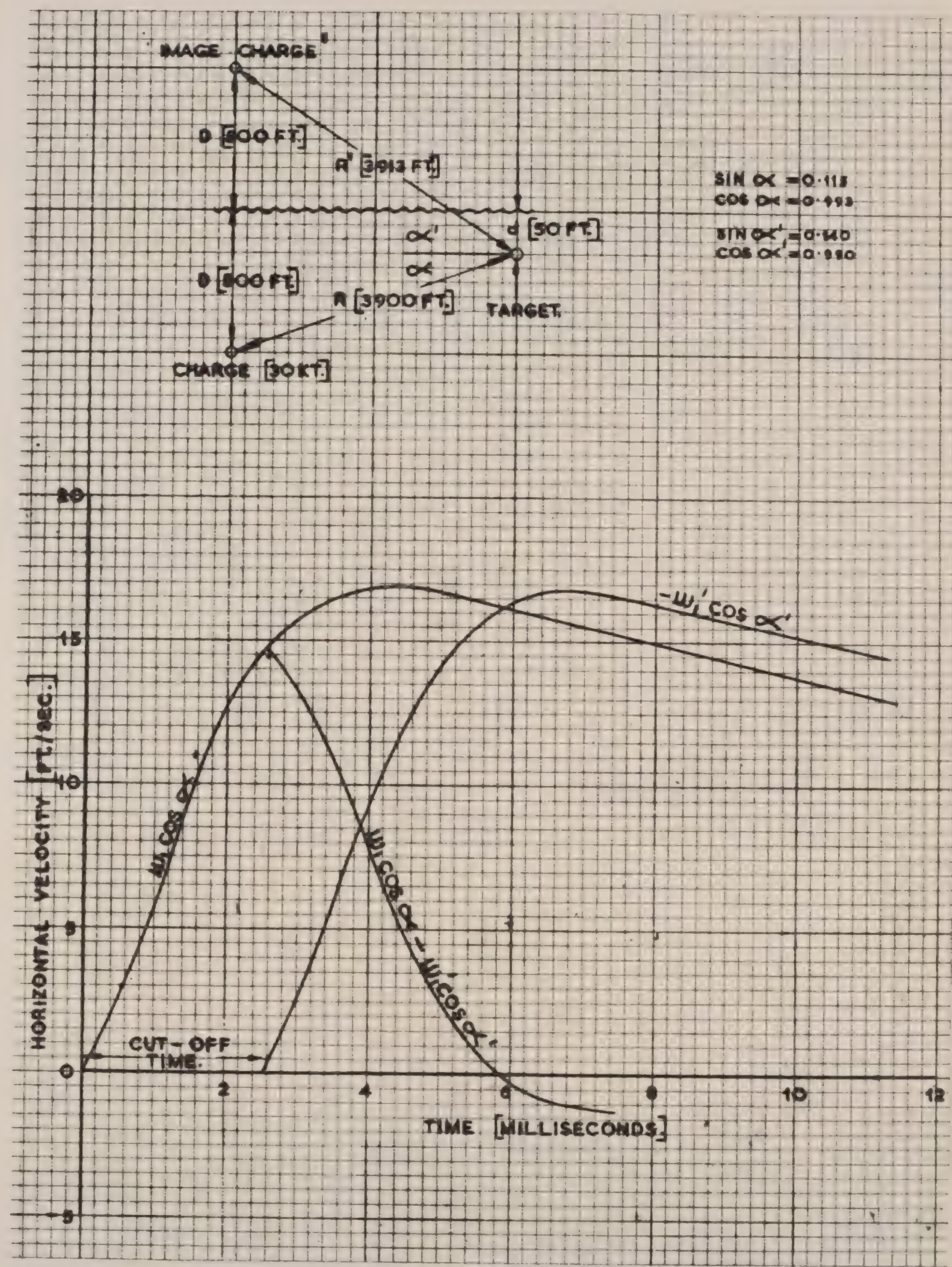


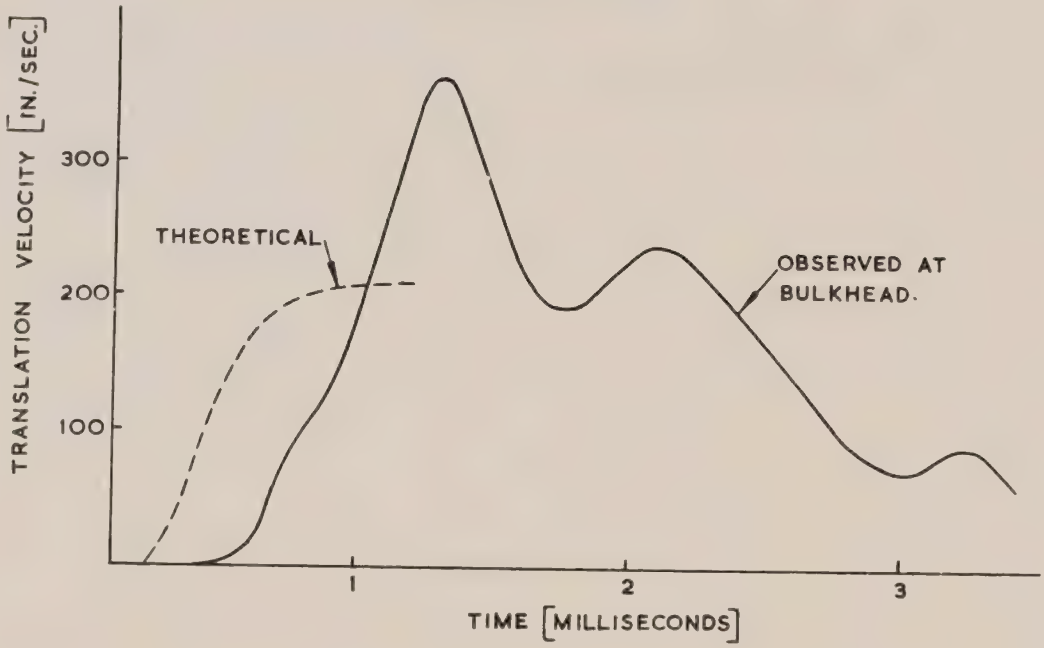
THE RESPONSE OF A CIRCULAR CYLINDER
OF NEUTRAL BUOYANCY



RIGID BODY VERTICAL MOTION



RIGID BODY HORIZONTAL MOTION



BULKHEAD VELOCITY

CHAPTER 5 - OTHER SUBMERGED STRUCTURES

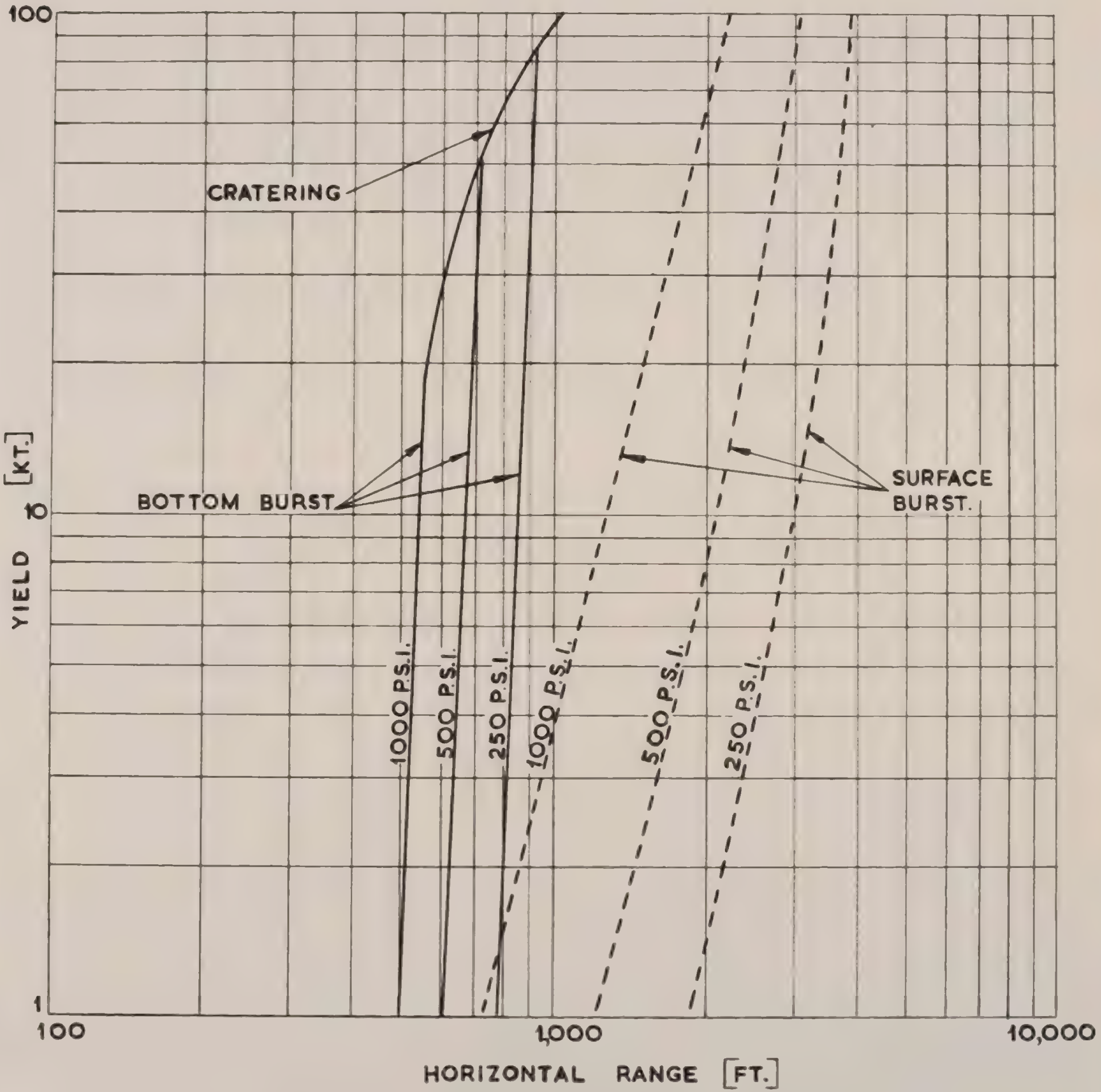
5.1 Introduction

Ships are the most important but are not the only structures susceptible to underwater explosions. Mines, Lock Gates, Underwater pipe lines etc., will usually be far more vulnerable to underwater than to airburst attack. Due to their smaller importance no experimental work has been carried out on the response of these items to underwater atomic attack. For this reason the damage criteria given in this chapter are inevitably based on a combination of theory and comparison with ships structure.

5.2 Mine Neutralisation

Structurally, a mine case is reasonably similar to a submarine but is always of considerably smaller size. For this reason it is to be expected that damage sufficient to cause mine neutralisation will result when the peak shock wave pressure exceeds the static collapse pressure of the mine case by a small margin. Reference (1) assumes that a peak pressure equal to the static collapse pressure will cause neutralisation and presents neutralisation curves for burst and mines on the bottom. These curves are very difficult to verify since the shallowness of the bursts of interest results in the underwater shock wave being very much affected by non-linear surface reflection (see Chapter 1).

The ranges at which collapse pressures of 250, 500 and 1,000 p.s.i. are reached, neglecting the presence of the bottom and using the only available theory of non-linear surface reflection (Data sheet 4.4 of the "Manual on the Effects of Atomic Weapons") and more than 3 times as great as those given by the curves in Capabilities. This suggests that the ranges given in Capabilities may be much too small but some allowance may have to be made for the so-called "shadow-band" effect. This is the name given to the rather curious effect that with explosions on the sea bed the peak pressures at given distances are lower adjacent to the sea bed than at greater elevations. This effect has been found in the region with an elevation less than about 10° above the burst and very limited evidence suggests that the peak shock wave pressures can be reduced to about 50% of the free water value. For this reason there is considerable doubt about the pressure distribution along the bottom with a bottom burst and the curves of Capabilities are reproduced in figures 1, 2 and 3 together with the curves for a burst in the surface calculated from figure 4.4.5 of the "Manual on the Effects of Atomic Weapons". These curves need to be treated with considerable reserve.



UNDERWATER MINEFIELD NEUTRALISATION,
50FT. DEPTH OF WATER, MINES ON BOTTOM

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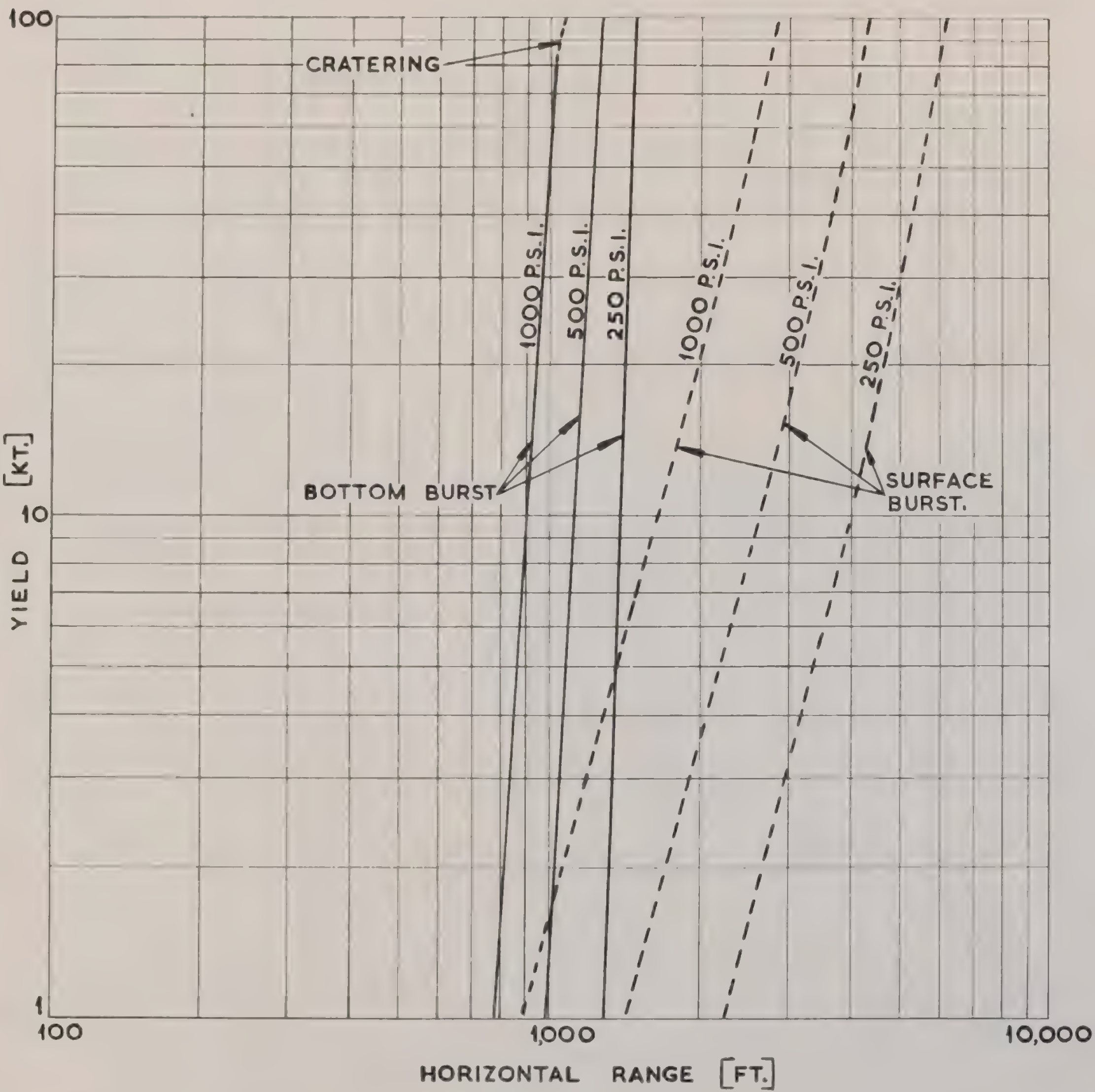
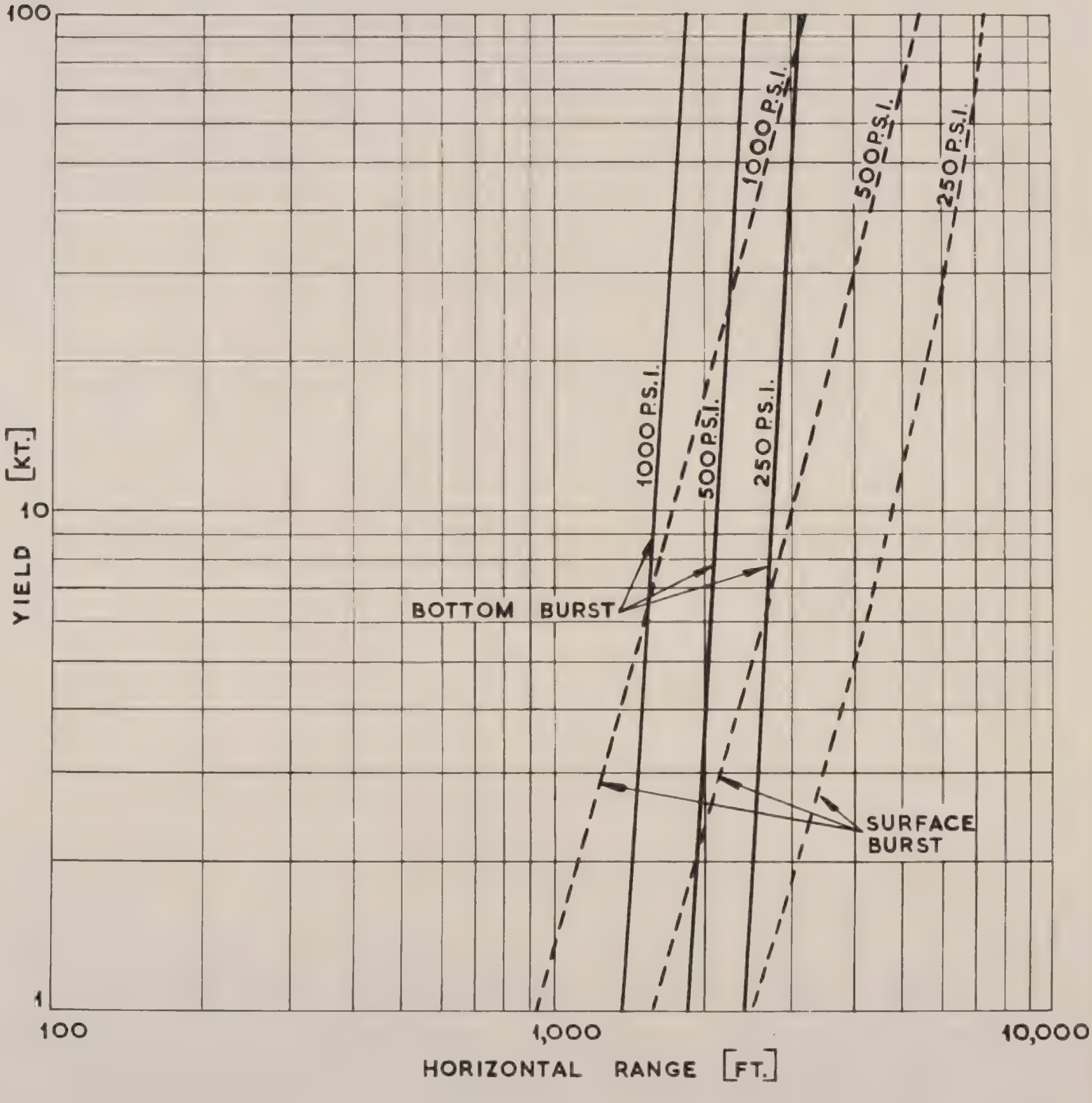


UNDERWATER MINEFIELD NEUTRALISATION,
100FT. DEPTH OF WATER, MINES ON BOTTOM



UNDERWATER MINEFIELD NEUTRALISATION,
200 FT. DEPTH OF WATER, MINES ON BOTTOM

5.3 Underwater Pipe Lines

Pipe lines that are completely filled with liquid are unlikely to be damaged unless within the crater. Gas filled pipe lines will be destroyed when the peak shock pressure exceeds the static collapse pressure by a small margin and the curves of figures 1, 2, 3 of Section 5.2 are applicable.

Pipes which are only partially filled with fluid will be collapsed on to the fluid at the destruction range for gas filled pipe lines. This may or may not lead to rupture depending on the proportion of liquid filled volume, ductility etc.

5.4 Dock Gates

The vulnerability of Dock Gates to underwater attack can be expected to be very sensitive to the height of water on both sides of the gate and to the type of gate. A gate of solid construction with the water level on the attacked side no higher than on the other side will be very little affected by the underwater shock at ranges where the surface waves would probably cause serious damage. For the same gate with the water level on the attacked side say 20 ft. higher than on the other side, the underwater shock can be expected to be the most important damaging agent unless the surface waves are increased by focussing, shelving bottom etc. In the latter case neglecting wave actions, the energy parameter E_H (Section 3.4) should give a fairly reliable damaging criterion with a value $E_H = 5.10^4$ ft./lb./ft.^{2} leading to rupture.

Dock Gates of watertight "egg box" construction can be expected to behave as ships' sides regardless of the relative heights of the water on the two sides. Damage leading to rupture could be expected on the attacked side when $E_H = 5.10^4$ ft.lb./ft.^{2} and this may or may not affect the operation of the gate depending upon the detail design. The side not attacked, if water backed, could be expected to be difficult to rupture, but the gate would probably be inoperable, although possibly still fairly watertight, long before rupturing stand-off is reached.

5.5 Dams

Concrete dams are likely to be more vulnerable to underwater shock than to airblast when the water level is higher than about half dam height. As the depth of water increases the vulnerability of the dam to an underwater burst increases. This is partly due to the increased static loading but is mainly due to the increased pressure pulse durations with deeper water. The great mass of dams makes it likely that damage will be governed by impulses rather than energy. This is assumed in Reference (1) where the following damage estimates are given for full concrete gravity dams (straight or slightly curved in plan) for a 20 K.T. underwater burst.

60 ft. high dam

Cracks are produced at a range of about 300 yds. Portions are cracked loose and displaced small distances at a range of about 200 yds.

150 ft. high dam

Cracks are produced at a range of about 500 yds. Portions are cracked loose and displaced sizeable distances at a range of about 200 yds.

500 ft. high dam

Cracks are produced at a range of about 1,300 yds. Portions are cracked loose and displaced large distances at a range of about 200 yds.

These estimates for cracking correspond to impulse values at the mean height facing the charge of 2.4, 4.7 and 6.5 p.s.i. seconds for 60, 150 and 500 ft. high dams respectively.

The cracking loose estimates correspond to impulse values at the same position of approximately 5.7, 32, 170 p.s.i. seconds for 60, 1,500 and 500 ft. high dam respectively.

5.6 Wave Damage

The question of wave damage to dock gates or indeed to any harbour installation requires an individual analysis of each target. The variables involved are water depth, bottom slope, wave height, wave length, target response characteristics, orientation of target to wave front, location of target relative to the point of wave breaking and variation in width of the channel or harbour.

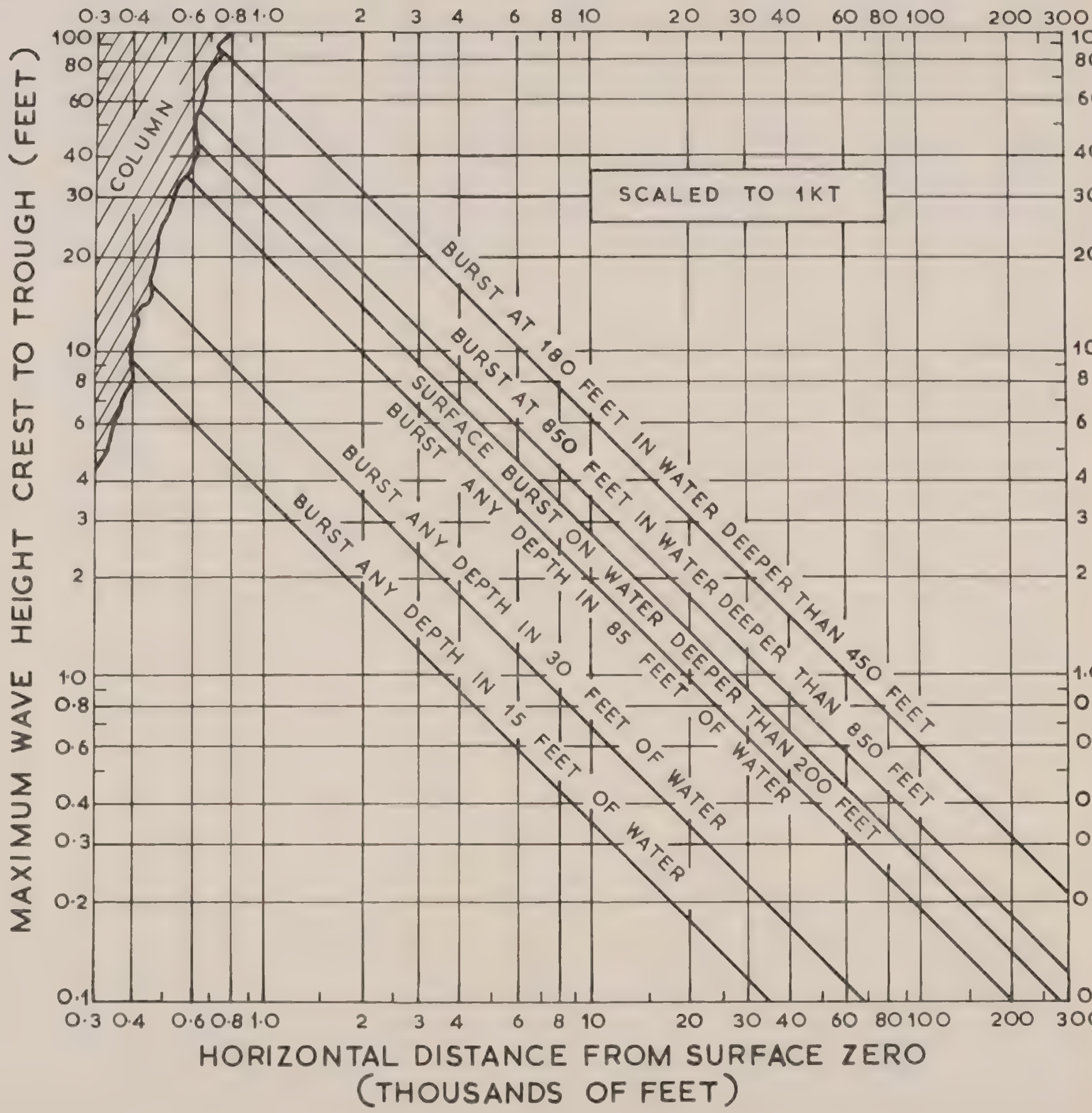
The estimation of water height in water of uniform depth is treated in Data Sheet 4.11 of the Manual on the Effects of Atomic Weapons. Further curves of estimated wave heights reproduced from "Capabilities" are given in figure 1. These latter curves do not entirely agree with the data given in M.E.A.W. and the disagreement reflects the degree of ignorance on this problem.

An example of the types of problem that arise is given by considering the effect of a 20 K.T. underwater explosion in the Bristol Channel. Provided this is carried out at least 20 miles from land in a favourable wind the problems arising from airblast, thermal, gamma radiation or underwater shock would be minor. The wave height reaching the Gower Peninsula and the Devon Coast would be around 2 ft. but the progress of this wave down the Bristol Channel could lead to a magnification of the wave height. The wave height in a slowly narrowing channel is inversely proportional to $(\text{breadth})^{\frac{1}{2}} \times (\text{depth})^{\frac{1}{4}}$, thus the wave height may reach about 30 ft. at Avonmouth and even higher further down the Severn.

This type of consideration may be a limiting factor in the use of atomic depth charges around coasts, and requires study.

Reference

1. Capabilities of Atomic Weapons. T.M.23 - 200 Revised Edition 1st June, 1955, Fig. 51, and November, 1957 Edition Fig. 2-34. (CONFIDENTIAL).



ESTIMATED WAVE HEIGHTS FOR WATER BURSTS

PART VI - DAMAGE BY THERMAL RADIATION

CONTENTS

SYMBOLS

a	Absorptivity
c	Specific heat (cal/gm/^{o}C)
D	Distance of target from energy source (feet)
E	Thermal energy of source (calories)
$\underline{E}$	Young's Modulus (tons/in^2)
$\bar{e}$	Emissivity
g	Absorption coefficient (of thermal radiation, for ground cut-off)
H	Newtonian cooling constant (cal/cm^2/sec/^{o}C)
H'	Heat transfer coefficient for convective cooling from a surface (cal/cm^2/sec/^{o}C)
I	Intensity of incident radiation (cal/cm^2/sec)
K	Thermal conductivity (cal/cm/sec/^{o}C)
k	Thermal diffusivity (cm^2/sec)
l	Half thickness of irradiated material (cm)
p	Radiant power (cal/sec)
p_{max}	Maximum radiant power (cal/sec)
Q	Radiant exposure (cal/cm^2)
q	Heat loss from a surface (cal/cm^2/sec)
R	Radius of fireball (feet)
r	Reflectivity
T	Temperature (^{o}C or as otherwise specified)
$\bar{T}$	Thermal transmittance of the atmosphere
$\bar{t}$	Thermal transmittance of material
t	Time (seconds)
t_{max}	Time to second thermal maximum (seconds)
W	Total weapon yield (kilotons)
x	Distance (within an irradiated material) (cm)
γ	Extinction coefficient (Bougier-Lambert Law)
θ	Temperature rise (^{o}C)
μ	Attenuation coefficient for thermal radiation
ρ	Density (gm/cc)

1.1 Characteristics of the Fireball

1.1.1 Formation

Owing to the great heat produced by a nuclear explosion all the materials in the weapon are converted into the gaseous form. Since the gases at the instant of explosion are restricted to the region occupied by the original constituents in the bomb, tremendous pressures are produced. Within a few millionths of a second of the detonation of the bomb the intensely hot gases at extremely high pressure formed in this manner appear as a roughly spherical highly luminous mass. This is the fireball (or ball of fire). Although the brightness decreases with time, after about 0.7 milliseconds the fireball from a 1-megaton nuclear bomb would appear to an observer 60 miles away to be more than thirty times as brilliant as the sun at noon (Reference (1)). As a general rule, the luminosity does not vary greatly with the energy (or yield) of the bomb. The surface temperatures attained, upon which the brightness depends, are thus not very different in spite of differences in the total amounts of energy released.

In the very earliest stages of its formation the temperature throughout the fireball is uniform. The energy produced as a result of fission (and fusion) can travel rapidly as radiation between any two points within the sphere of hot gases, and so there are no appreciable temperature gradients. Because of the uniform temperature the system is referred to as an isothermal sphere which, at this stage, is identical with the fireball.

As the fireball from an air burst grows, a blast wave develops in the air and the shock front at first coincides with the surface of the iso thermal spheres and the fireball. However, when the temperature falls below about 300,000°C the shock front advances more rapidly than the isothermal sphere. As the shock front moves ahead of the isothermal sphere it compresses the air before it to about ten times its normal density and in doing so raises its temperature to a sufficient extent to render it incandescent. The fireball now consists of two concentric regions. The inner (hotter) region is the isothermal sphere of uniform temperature, and this is surrounded by a layer of luminous shock-heated air at a somewhat lower, but still very high temperature. As the shock expands, its temperature continues to fall until a time is reached when the shock is no longer incandescent (the first minimum), and then becomes transparent to the radiation of the hotter internal sphere. From this time the temperature of the visible fireball again rises to a peak (the second maximum), and finally falls as the inner sphere expands and cools. Only a very small proportion of the total thermal energy release of a true air burst occurs before the first minimum. The rest is released during the second or main thermal pulse.

For a surface burst having the same yield as an air burst, the presence of the earth's surface results in a reduced thermal radiation emission and a cooler fireball when viewed from that surface. This is due primarily to heat transfer to the soil or water, the distortion of the fireball by the reflected shock wave, and the partial obscuration of the fireball by dirt and dust (or water) thrown up by the blast wave.

In underground bursts the fireball is obscured by the earth column, and therefore thermal radiation effects are negligible. Nearly all of the thermal radiation is absorbed in fusing and vaporizing the earth.

Thermal radiation from an underwater detonation is increasingly absorbed in vaporization and dissociation of the surrounding medium as the depth of burst is increased. Its direct effects are insignificant for most practical purposes; e.g. for a 20-KT burst ninety feet below the surface of water, thermal effects are negligible. (Reference (2)).

References

(1) Effects of Nuclear Weapons, U.S.A.E.C. (1957) p.19.

(2) Capabilities of Atomic Weapons, U.S. Dept. of the Army, TM 23-200 (1957) p.3 - 1. (Confidential)

1.1.2 Radius of the Fireball

A detailed discussion of the growth of the fireball will be found in M.E.A.W. Data Sheet 3.1.2, and an unclassified account is given in Reference (1).

The maximum size of the luminous fireball may be represented by a scaling law in the form of the equation:-

$$\frac{R}{R_o} = \left(\frac{W}{W_o}\right)^{0.4}$$

where R is the maximum radius of the luminous fireball for a bomb with a total energy yield of W kilotons, and R_o is the (known) value for a reference bomb of W_o kilotons.

By making use of this scaling law, together with the results obtained at various nuclear test explosions, the following relationship may be derived (Reference (1)):-

$$R \text{ (feet)} = 230\ W^{0.4}$$

From this expression the maximum radius of the luminous fireball (in feet) for a bomb energy of W kilotons may be calculated.

The manner in which the radius increases with time, in the period from approximately 0.1 millisecond to 1 second after detonation of a 20-KT nuclear bomb is shown in Figure 1, taken from Reference (2).

The data given above are thought to be reasonably accurate at heights up to 50,000 ft. For bursts at very high altitudes (of the order of 100,000 ft.) it has been estimated that a significant amount of thermal energy will be emitted before the first minimum, and that the radius of the fireball may be three times as great. (Reference M.E.A.W. Data Sheet 3.1.5).

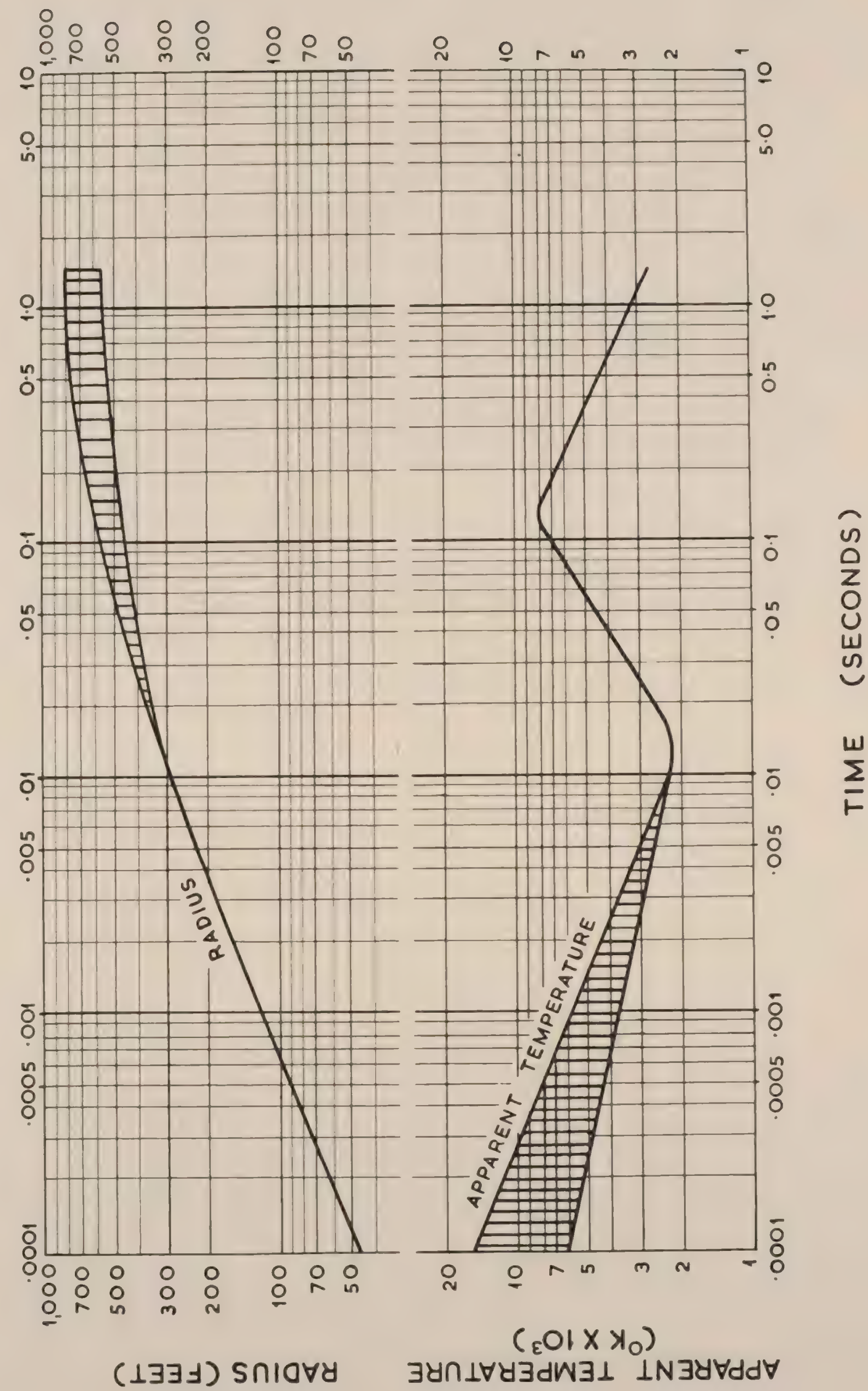
The fireball radius may be used to estimate the height of burst above which a given explosion will cause negligible local fallout. For yields less than 100 KT, the height of burst at which fallout ceases to be a significant military hazard is about 100 $W^{\frac{1}{3}}$ feet. For yields in excess of 100 KT the height of burst at which fallout is not a military hazard is not well defined, but in the absence of data the height of burst may be conservatively taken as 180 $W^{0.4}$ feet.

It must not be assumed that weapons burst above these specified heights will never present a residual radiation problem, for neutron-induced radioactivity can be very intense in a relatively small area around ground zero. (For details see Part VII, Chapter 3, Section 3.2).

Reference

(1) Effects of Nuclear Weapons U.S.A.E.C. (1957) p.66.

(2) Capabilities of Atomic Weapons. U.S. Department of the Army, Manual TM 23-200 (1957). (Confidential)



RADIUS AND APPARENT SURFACE TEMPERATURE OF FIREBALL AS A FUNCTION OF TIME (20 KT AIR BURST)

1.1.3 Temperature of the Fireball

In Section 1.1.1 the fireball was described as emitting thermal radiation in a pulse characterised by a rapid rise to a first maximum, a decline to a minimum, another rise to a second maximum and a subsequent final decline. The first phase of this pulse occurs so very rapidly that less than 1% of the total thermal radiation is emitted. Consequently it is the second phase of the pulse which is of interest in weapons effects considerations at altitudes in the troposphere and lower stratosphere.

Throughout, the fireball may be considered to radiate essentially though not ideally as a black body, for which the radiant power is proportional to the radiating area and to the fourth power of the temperature. After the minimum the radiating radius and area increase relatively slowly, so that the radiant power is predominantly determined by the temperature cycle of the fireball. An illustration of the apparent temperature and fireball radius as a function of time for a 20-KT airburst is shown in Figure 1 of Section 1.1.2. It should be emphasised, however, that the actual radiating area may vary substantially from that of the luminous fireball.

It has been found that both the time to minimum and the time to the second maximum are proportional to the square root of the weapon yield. The respective temperatures, however, are essentially independent of explosion energy.

For details of the shape of the thermal pulse the reader is referred to Section 3.2.1 of Chapter 3. Details of the colour temperature of the fireball depend upon the location of the burst, in a manner outlined in the following section 1.2.1.

1.2. Radiation from the Fireball

1.2.1. Nature of the Radiation

The thermal (or visual-thermal) radiation output from a nuclear explosion consists of an initial ultra high temperature flash (colour about 300,000°K) of very short duration, followed by the radiation from the fireball, which may vary in duration from a fraction of a second to twenty seconds, according to the size of the weapon. (For details see Section 1.1.3 and M.E.A.W. Data Sheets 3.1 and 3.3).

In very high altitude bursts, the magnitude and duration of the flash are enhanced at the expense of blast energy and radiation from the fireball (M.E.A.W. Data Sheets 3.1C and 3.3C), but apart from this special case the flash effect can generally be ignored. An exception however, is the flash effect on the human eye, which is considered in Chapter 7, Section 7.8.

The emission from the fireball is roughly "black-body" in spectral distribution, with a colour temperature of mean value about 6,000°K for an air burst, or 3,000°K for a surface burst. At wavelengths below about 0.3 micron the radiation is very heavily attenuated by the atmosphere, and the output below this value may usually be ignored. For an air burst, about 10% of the radiation will be in the transmitted ultra-violet (0.3 to 0.4 micron), and the rest will be equally divided between the visual (0.4 to 0.75 micron) and the infra-red (over 0.75 micron). For a surface burst (as viewed by a ground observer) there will be negligible ultra-violet, about 10% visible, and 90% infra-red radiation. A surface burst viewed from the air may exhibit a spectrum more nearly like an airburst.

1.2.2. Attenuation of Thermal Radiation

The thermal energy from a nuclear explosion falling upon a given area will diminish with increasing distance from the explosion for two reasons.

Firstly, the radiation will spread over an ever-increasing area as it travels away from the fireball, and will be reduced according to the inverse square law of distance.

Secondly, allowance must be made for the attenuation of the radiation by the atmosphere. The atmospheric transmittance (T) is defined as the fraction of the radiant exposure received at a given distance after passage through the atmosphere, relative to that which would have been received at the same distance if no atmosphere were present. Atmospheric transmittance depends upon several factors; among these are: water vapour and carbon dioxide absorption of infra-red radiation, ozone absorption of ultra-violet radiation, and multiple scattering of all radiation. All these factors vary with distance and the composition of the atmosphere. Scattering is produced by the reflection and refraction of light rays by certain atmospheric constituents such as dust, smoke and fog. Interactions such as scattering which divert the rays from their original paths result in a diffuse rather than direct transmission of the radiation. As a result a receiver which has a large field of view (i.e. most military targets) receives radiation which is scattered toward it from many angles as well as the directly transmitted radiation. Since the mechanisms of absorption and

scattering are wavelength dependent, the atmospheric transmittance depends not only upon the atmospheric conditions, but also upon the spectral distribution of the weapon's radiation. In Figure 1 the atmospheric transmittance is plotted as a function of the slant range for air and surface bursts. For each type of burst three sets of atmospheric conditions are assumed. It is believed that these conditions represent the average of the extremes normally encountered in natural atmospheres. These conditions correspond to a visibility of 50 miles and a water vapour concentration of 5 grammes/cubic meter; 10 miles visibility and 10 grammes/cubic meter water vapour concentration; and 2 miles visibility and 25 grammes/cubic meter of water vapour concentration. The curves of Figure 1 are plotted to slant ranges equal to half the visibility for the three visibility conditions. The reason for this is that the empirical relationships used to obtain the transmittance values have not been verified for ranges beyond half the visibility. As a result the curves cannot be extrapolated to greater distances with any confidence. If the curves are extended beyond half the visibility, there is reason to believe that the values of transmittance would be too high. Where cloud cover is appreciable or the air contains large quantities of fog or industrial haze, knowlecge of the interactions with the radiation is too limited to provide estimates of atmospheric transmittance.

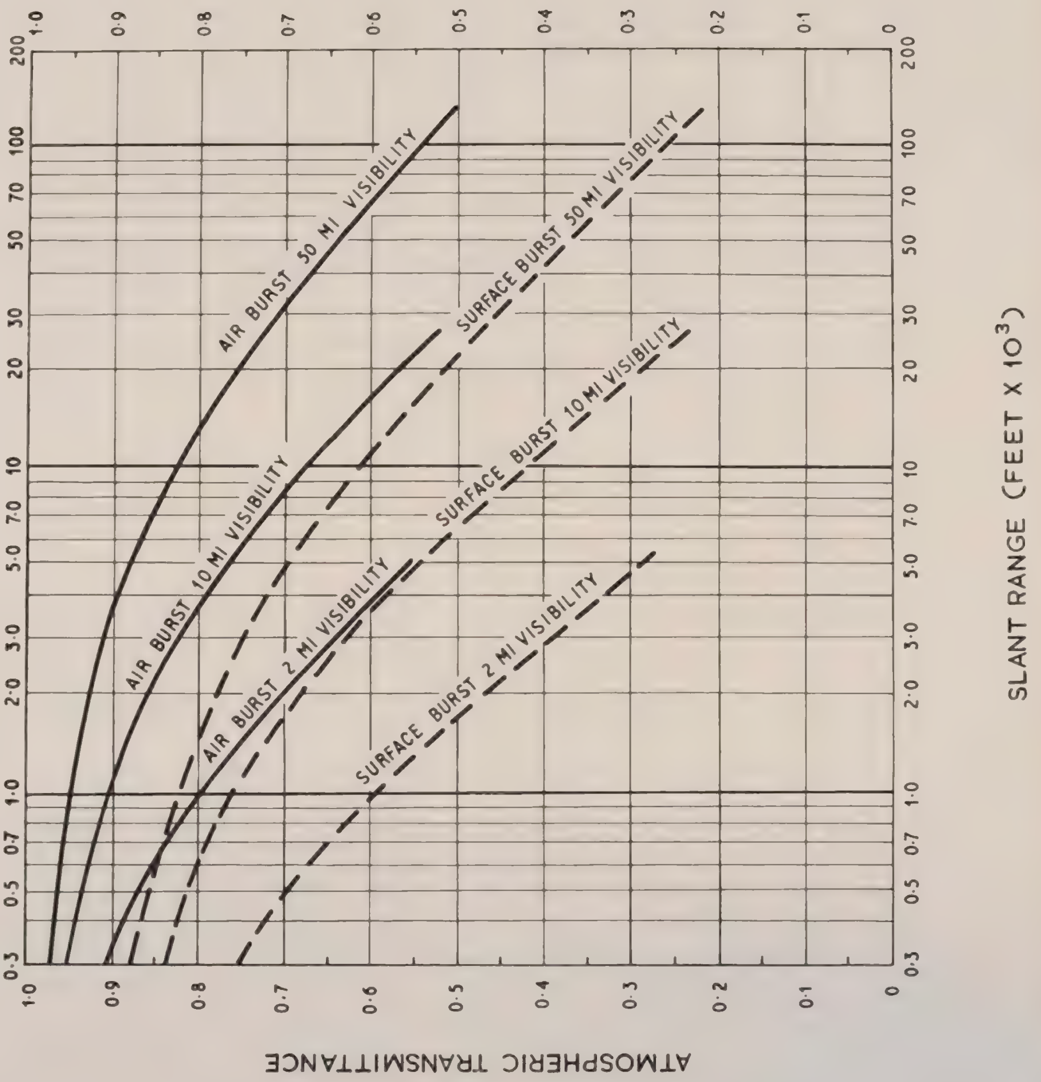
A discussion of the protection given by smoke and fog is given in section 2.4 of Chapter 2.

Some recent laboratory work is described in Reference (2).

References:

(1) Capabilities of Atomic Weapons (1957), U.S. Department of the Army. TM.23-200, page 3-2 (Confidential).

(2) Atmospheric Attenuation of Radiation. C.D.E.E. Porton Technical Paper (R)14. (Restricted).



ATMOSPHERIC TRANSMITTANCE AS A FUNCTION OF SLANT RANGE FOR AIR AND SURFACE BURSTS

2.2. Diffuse Atmospheric Transmission. Windows.

For an accurate assessment of the amount of thermal radiation falling on a surface inclined at an angle to the source or upon a surface receiving radiation from a limited field of view (e.g. through a window) it is necessary to know the polar distribution of the radiation on arrival.

Some limited experimental work suggests that the peak intensity of the thermal radiation reaching a surface from a field of view β radians diameter directed towards the source, is given by:-

$$\overline{T}_\beta = \overline{T} + g\,(1 - \overline{T})\,(1 - e^{-\beta})$$

where $\overline{T}$ is the specular transmittance

$\overline{T}_\beta$ is the apparent transmittence for the field of view β.

$\overline{T} = e^{-\mu D}$ where μ is the mean attenuation coefficient for all wavelengths in the fireball spectrum and D is the distance of the receiving surface from the point of burst.

In the formula above $(1 - \overline{T})$ represents the amount of scattered radiation. g is a constant varying between $\frac{1}{2}$ and 1 representing the loss of scattered light to the ground. $(1 - e^{-\beta})$ is an empirical correction, determined by experiment, for the fraction of the scattered radiation coming from the field of view β. Extended experiments in the U.K. seem to suggest that doses estimated in this way will in general overestimate the diffuse dose.

A more detailed treatment of the above formula is given in M.E.A.W. Data Sheet 3.5A and M.E.A.W. Fig. 3.5.2 shows T_β as a function of $\overline{T}$ for various values of β and g.

Detailed mathematical treatments of the radiation scattering problem have been attempted in References (1) and (2).

A less sophisticated method of attack is to assume the radiation reaches the surface in three ways:-

(a) By direct specular transmission.

(b) By two rectilinear (attenuated paths) with one single scattering between them.

(c) The residual scattered radiation is then assumed to be isotropically diffuse and to reach the source uniformly from all directions.

Calculations based on this method of analysis are likely to be adequately accurate for many purposes. Some experimental and theoretical results are discussed in Reference (3).

References

(1) Sliepcevich, C.W. et alia. Attenuation of Thermal Radiation by a Dispersion of Oil Particles. Parts I and II. University of Michigan, 1954. (Unclassified).

(2) Smith, M.G. The Six Flux Method as an Approximation to the Transport Equation. A.R.D.E. Memorandum (B) 23/58. (Restricted/Discreet).

(3) Dorman, R.G. and Wootten, N.W. Atmospheric Attenuation of Radiation. C.D.E.E. Porton Technical Paper (R) 14. (Restricted).

2.4. Effectiveness of Shielding

Apart from the effects of scattering the thermal radiation from a nuclear explosion travels in straight lines from the fireball. Any solid opaque material such as a wall, a hill, or a tree between a given target and the fireball may act as a shield and provide protection from thermal radiation. Instances of such shielding observed after a nuclear explosion in Japan are given in Reference (1).

A shield which merely intervenes between a given target and the ball of fire, but does not surround the target, may not be entirely effective under hazy atmospheric conditions. A large proportion of the thermal radiation received, especially at considerable distances from the explosion, has undergone scattering (see Sections 2.1, 2.2, and 2.3) and will arrive from all directions, not merely that from the point of burst. It should also be borne in mind that at close ranges, where the fireball subtends a relatively large angle, the shadowing effects of intervening objects are less than are experienced with the sun.

An assessment of the value to troops of slit trenches, as protection against thermal and gamma radiations from nuclear explosions, is given in Reference (2). It is concluded that open slit trenches afford considerable overall protection to personnel against thermal and gamma effects of nuclear weapons. Even when least effective (i.e. against high air bursts), they may be expected to save about 40% of the total casualties (from nuclear and thermal radiation) which would result from all men being in the open. This figure increases with decreasing burst height, up to a maximum of about 97% for low air bursts. Trenches with thermal screens afford much greater protection than open trenches against high air bursts, but about the same protection against low air bursts.

In a report on the vulnerability of Armoured Fighting Vehicles and their crews to nuclear weapons (Reference (3)), an assessment is made of the protection afforded against thermal radiation. It is concluded that closed-down vehicles give good protection against thermal radiation, but that there is a possibility of burns being caused by the transmission of radiation through optical instruments.

Transparent materials such as glass and plastics allow thermal radiation to pass through only slightly attenuated. Methods of treating window-glass to provide heat radiation shields are described in Reference (4). These methods consist in applying a coating to the window which reduces the radiation transmitted and scatters the part which is transmitted. Thus not only is the total quantity of heat entering the room reduced, but its intensity is more evenly distributed. The best coatings for this purpose are white, and those that last longest are of the high gloss or cement paint type; emulsion paints are ineffective. The protection is reduced if the windows are blown out by the blast wave before all the thermal energy is delivered.

References

(1) Effects of Nuclear Weapons. U.S.A.E.C., 1957, pages 312-316.

(2) A.O.R.G. Report No. 12/55 "The Protective Value to Personnel of Slit Trenches against Thermal and Gamma Radiation Effects of Nuclear Explosions. (Secret/U.K. Eyes Only)

(3) A.O.R.G. Report No. 4/58 - "The Vulnerability of Armoured Fighting Vehicles and Their Crews to Nuclear Weapons". (Secret/Discreet)

(4) Joint Fire Research Organisation S.R. Note 28/1956 "Heat Radiation Shields for Defence against Atomic Explosions". Simms D.L., Hinkley, P.L., and Weston, M.A. (Confidential).

CHAPTER 3 - THE TEMPERATURE RISE OF IRRADIATED MATERIALS

3.1. Introduction

There are many important physical properties which determine the temperature rise of irradiated materials. Among these are:-

(a) the intensity of the incident radiation; (I cal/cm^2/sec).

(b) the duration of the irradiation; (t secs).

(c) the reflectivity or absorptivity of the material; (r) or (a).

(d) the transmittance of the material; ($\bar{t}$).

(e) the thermal properties of the material, i.e.

thermal conductivity	(K cal/cm/sec/$^\circ$C)
specific heat	(c cal/gm/$^\circ$C)
density	(ρ gm/cc)

(f) the thickness of the material; (2 ℓ cm).

(g) the heat transfer coefficient for cooling losses from the surface by convection and re-radiation. (H cal/cm^2/sec/$^\circ$C). (The Newtonian Cooling Constant).

(h) the chemical heating if the material is not inert.

In calculating the temperature rise of an irradiated solid it is necessary to make certain simplifying assumptions. These assumptions cannot be made without loss of accuracy, but when thermal damage from nuclear explosions is estimated, only approximate information is available on such matters as the effect of the atmosphere on the transmission of raidation and the actual thermal yield of the bomb. Useful quantitative results can be obtained since prediction errors are likely to be relatively small compared with various other practical uncertainties.

3.2. Factors Influencing the Temperature Rise

3.2.1. Irradiation Intensity

The shape of the thermal pulse after the radiant power minimum is sufficiently similar for nuclear detonations that a single curve may represent the time distribution of radiant power emitted (Figure 1). This curve has been developed by using ratios. The ratio $^p/p$ max is plotted against the ratio $^t/t$ max, where $^p/p$ max is the ratio of the radiant power at a given time to the maximum radiant power, and $^t/t$ max is the ratio of time after detonation to the time of the second thermal maximum after that detonation.

The percentage of the total thermal radiation emitted as a function of the ratio $^t/t$ max is also shown on Figure 1. From this figure it is seen that approximately 20% of the total emission occurs up to the time of the second power maximum, whereas approximately 80% is emitted prior to 10 times the time to the second maximum. By this time the rate of delivery has dropped to such a low value that the remaining energy is no longer of significance in damage production, although the fireball still appears brilliant to the eye until approximately 50^t max.

It has been found that both the time to the minimum and the time to the second maximum are proportional to the square root of the weapon yield. Thus for airbursts at altitudes of burst below about 50,000 ft., the time to minimum is $0.0027W^{\frac{1}{2}}$ seconds. The time to the second maximum is $0.032W^{\frac{1}{2}}$ seconds. (See Figure 2: these curves may also be used for surface bursts.) It should be noted that for weapon yields lower than approximately 6 KT the actual values of t max may be as much as 30% higher than those given by Figure 2. This is caused by the higher mass-to-yield ratio characteristic of low yield weapons. These relations indicate that a 1 megaton weapon delivers its thermal radiation over a period 32 times as great as does a 1 KT weapon. Hence it is to be expected that the thermal energy required to produce a given degree of damage will increase with the energy yield of the explosion, e.g. see Table 2 of Section 4.2.1 Chapter 4 - Critical Radiant Exposure Values for various Fabrics.

References

(1) Capabilities of Atomic Weapons (1957) - U.S. Dept. of the Army, TM 23-200, p. 3-1. (Confidential).

TABLE 1

Percentage absorption of different materials for different wavelengths of thermal radiation

Material	Source of Temperature			
	Ignition point	Average fire	Surface burst AW	Air burst AW
	800°K	1,100°K	3,000°K	6,000°K
	Per Cent	Per Cent	Per Cent	Per Cent
Gaberdine (Forestry Green)	-	70	65	75
Cotton Twill (White)	-	45	35	30
Cotton Twill (Grey)	60	-	65	80
Cotton Sateen (Dark)	-	40	55	75
Serge (Dark Blue)	-	65	70	85
Fibre Insulating Board	71	-	35	40
Oak	-	70	45	60
Mahogany	74	-	40	55
Steel (polished)	10	20	40	45
" (oxidised)	80	-	-	-
Copper	5	13	25	-
Aluminium (polished)	8	18	35	45
" (oxidised)	75	-	-	-

This means that whilst the colour of a material may be a guide to its reflectivity to the visible portion in the spectrum, it may not be relevant to the reflectivity in the infra-red. In addition, if the absorptivity of the surface varies with its temperature, as for example the charring of wood, discoloration of paints, surface oxidation of metal, then substantial errors may be made in estimating the temperature rise. This is particularly true for materials which have a low absorptivity, where the effects of only a slight deterioration in the surface quality can be important.

Empirical correction factors have been obtained for cellulosic materials (Reference (1)) where the changes occur gradually. These are given in Table 2. For shorter exposure times the effective absorption is less. In the absence of any other information the mean value of the initial and final absorptivities should be used.

TABLE 2

Correction Factors for Absorption
by Cellulosic Materials

Material	For time of irradiation greater than (seconds)	Effective Absorption factor for Radiation of 6000°K
African mahogany	10	0.95
Western Red Cedar	7	0.7
European Oak	10	0.7
White Cotton	3	0.3

Further data on absorptivities of metal and painted metal surfaces are given in Sections 4.3.1 and 4.3.2 respectively, of Chapter 4.

(b) Transmittance

The great majority of materials may be considered opaque to radiation. The exceptions are glass, and perspex and similar plastics, although many fabrics - especially those of loose weave and light weight - transmit some of the radiation directly, as given in Reference (8).

Few figures are available for the value of γ, the extinction coefficient, for most non-combustibles except glass (Reference (2)). Some figures which are not generally available, for plastics for wavelengths in the range 500-950 microns are given in Table 3 (from Reference (3)).

TABLE 3

Some Extinction Coefficients of Plastic Materials

Plastic	Wavelength 500-950 microns Extinction Coefficient (cm^{-1})
Methyl methacrylate (Perspex)	0.66
Allyl alcohol	0.32
Cellulose acetate butyrate	2.4
Cellulose acetate	1.9
Cellulose nitrate	1.3
Cellulose propionate	4.3
Ethyl cellulose	1.6
Polystyrene	2.4

Some materials normally thought of as opaque, for example wood, are influenced in their normal behaviour by transmittance, particularly where the exposure is short (Reference (4)). The fact that radiation is not all absorbed at the surface may mean that the temperature in the immediate interior is slightly higher than for an opaque material, whilst the surface temperature will be slightly lower.

(c) Thermal conductivity

The thermal conductivity of all materials varies with the temperature; for most pure metals it might be expected to be inversely proportional to the absolute temperature. Little information on this is available for non-metals, but the values may change if a vigorous chemical reaction should occur. If moisture is present, the thermal conductivity of wood or insulating materials may be increased significantly (Reference (5)). The presence of an air gap in the material will decrease its conductivity considerably. For short exposures, such as are being considered here, air gaps may prevent heat penetrating to the interior altogether. This is often of great importance in preventing burns to the skin through clothing.

(d) Density

This may usually be taken as constant.

(e) Specific heat

This may vary with temperature. If the material holds moisture the apparent specific heat may increase considerably (Reference (6)). See also Section 3.2.4 of this chapter.

Table 4 gives values of the thermal constants for a wide range of materials (Reference (7)).

Reference

(1) Simms, D.L., Law, Margaret and Hinkley, P.L. The Effect of Absorptivity on the Ignition of Materials by Radiation. J.F.R.O. F.R. Note No. 308/1957.

(2) Smithsonian Physical Tables, Washington, 1954, page 512.

(3) Lawrence, E.K. Analytical Study of Flame Initiation (M.Sc. Thesis) Department of Chemical Engineering, Massachusetts Institute of Technology, U.S.A. (1952).

(4) Gardon, R. Thermal Damage Initiation in Organic Materials Technical Report No. 2. Fuel Research Laboratory, Massachusetts Institute of Technology, U.S.A.

(5) Maclean, J.D. "Thermal Conductivity of Wood". Heating, Piping and Air Conditioning, 1941, Vol. 13, pages 380-391.

(6) Hearman, R.F.S. and Burchan, J.N. "Specific Heat and Heat of Wetting of Wood". Nature, November 26, 1955, page 978.

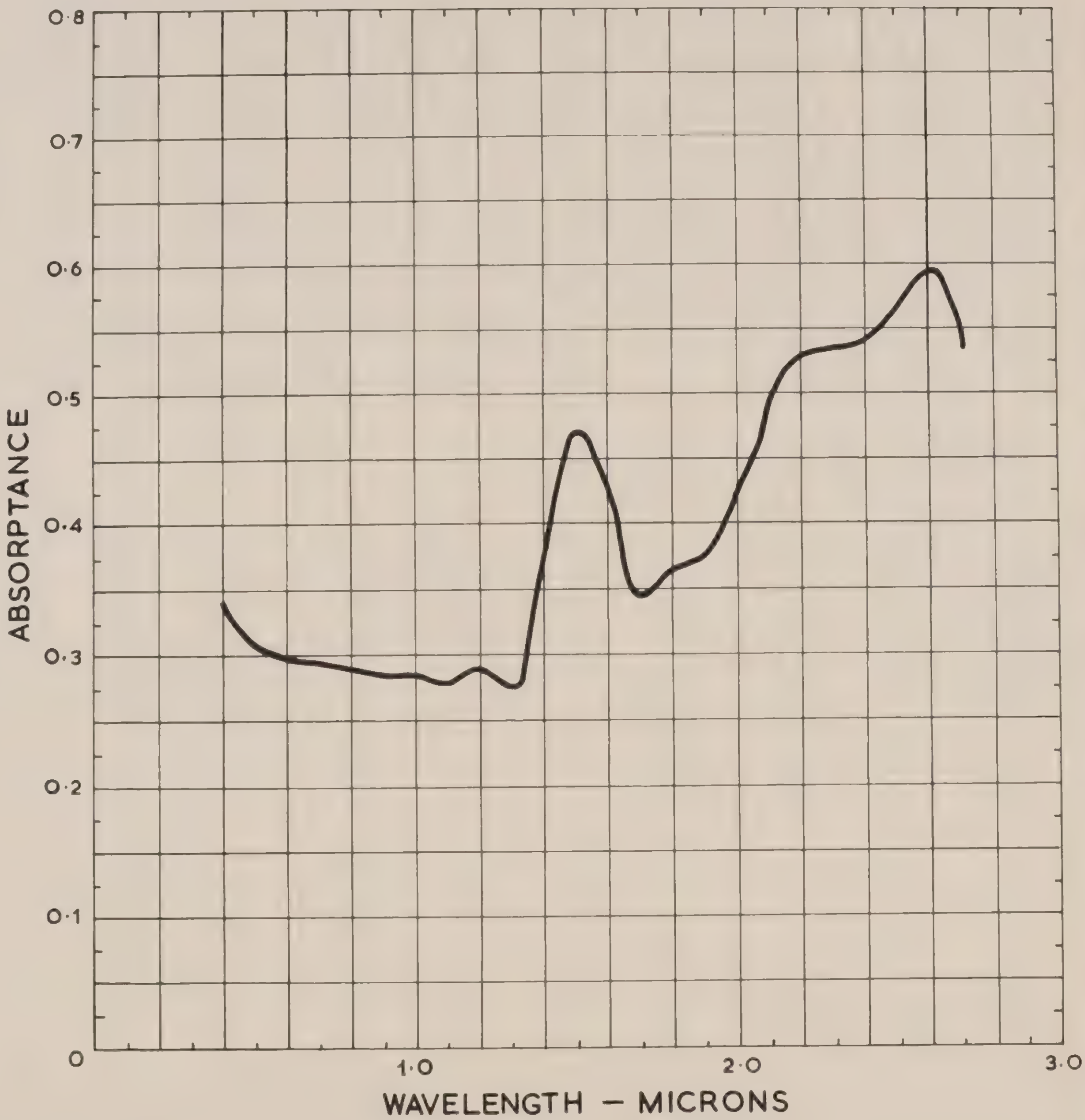
(7) Wilkes, G.B. "Heat Insulation". John Wiley, 1950.

(8) Richards, H.R., and Fuoco R., "An evaluation of some cotton textile fabrics". Defence Research Chemical Laboratories, Report No. 278, Ottawa, April 1958.

TABLE 4

Thermal Constants for Various Materials

Material	Density ρ	Specific heat c	Conductivity K	Diffusivity k
	gm/cm^3	cal/gm	$cal/cm/sec/^{\circ}C$	cm^2/sec
WOODS				
Western red cedar	0.36	0.34	21×10^{-5}	1.73×10^{-3}
American white wood	0.47	0.34	29×10^{-5}	2.0×10^{-3}
African mahogany	0.56	0.34	33×10^{-5}	2.0×10^{-3}
Freijo	0.58	0.34	33×10^{-5}	2.0×10^{-3}
Oak	0.61	0.34	35×10^{-5}	2.0×10^{-3}
Iroko	0.72	0.34	41×10^{-5}	2.0×10^{-3}
METALS				
Copper	8.9	0.09	0.93	[illegible].14
Silver	10.5	0.56	1.00	0.171
Gold	9.30	0.03	0.93	1.18
Magnesium	1.7	0.24	0.38	0.91
Aluminium	2.7	0.21	0.48	0.86
Zinc	7.1	0.92	0.27	0.111
Tin	7.3	0.53	0.15	0.038
Brass 70 : 30	8.5	0.09	0.25	0.33
Platinum	21.5	0.03	0.17	0.25
Lead	11.3	0.03	0.08	0.25
(0.1%C) mild steel	7.9	0.12	0.11	0.12
Cast iron	7.4	0.14	0.12	0.12
Bismuth	9.8	0.03	0.02	0.07
Mercury	13.6	0.03	0.02	0.04
BUILDING MATERIALS				
Fibre insulating board	0.24	0.34	$[illegible].5 \times 10^{-5}$	1.04×10^{-3}
Brick	1.44-2.24	0.20-0.22	$13-32 \times 10^{-4}$	$44-67 \times 10^{-4}$
Concrete (gravel)	2.16-2.29	0.22-0.23	$57-33 \times 10^{-4}$	$65-120 \times 10^{-4}$
Foamed slag concrete	1.04	0.23	5.7×10^{-4}	24×10^{-4}
Cellular concrete	0.64	0.25	3.4×10^{-4}	21×10^{-4}
Glass	2.11-2.6	0.16	2.1×10^{-3}	5.2×10^{-3}
Slag wool	0.19-0.30	0.18	$0.9-1.4 \times 10^{-4}$	$26-27 \times 10^{-4}$
BOARDS OR BLOCKS				
Asbestos paper				
Corrugated	0.25	0.24	1.46×10^{-4}	24.2×10^{-4}
Laminated	0.35	0.24	1.5×10^{-4}	18×10^{-4}
Corkboard	0.13	0.42	1.0×10^{-4}	18×10^{-4}
Fibre glass	0.032	0.13	8.5×10^{-5}	1.9×10^{-2}
POWDERS				
Charcoal	0.18	0.25	1.2×10^{-4}	26.8×10^{-4}
Ground cork	0.15	0.48	1×10^{-4}	0.0014
Soil (Average)	2.5	0.2	23×10^{-4}	0.0046
Soil (Sandy dry)	1.65	0.19	6.3×10^{-4}	0.0020
Soil (Sandy moist 8%)	1.75	0.24	14×10^{-4}	0.0033



VARIATION OF ABSORPTANCE WITH WAVELENGTH
FOR A WHITE COTTON TWILL

3.2.3. Homogeneity of the material

The most important types of non-homogeneous materials are thin films on a combustible base material, and clothing on the body. A thin film on the surface of the material may have two effects (Reference (1)).

(a) If it is opaque it may change the emissivity and absorptivity of the material underneath. In estimating the temperature rise, the emissivity of the film should be taken, provided that the film is not rapidly destroyed by the heat.

(b) It may, if applied sufficiently thickly, remove the capacity of transparent material to transmit radiant heat.

Either effect may alter the rise in temperature of the surface. In general, thin films of good conductors have little effect on bad conductors, whilst a thin film of a bad conductor may have a marked effect on both good and bad conductors. (Reference (2)). The most effective barrier is one of a high thermal capacity and low conductivity, (Reference (3)). It is important to realise that changing the base material will change the temperature rise in both materials.

References

(1) Leedy, R.N. "Control of Radiant Heat by Surface Finish". Westinghouse Engineer, 1954, Vol. 14, pages 147-157.

(2) Carslaw, H.S. and Jaeger, J. C. "Conduction of Heat in Solids". Oxford, 1948, Clarendon Press, pages 54-55.

(3) Pickard, R. W. "The Thermal Insulation Afforded by a Fire Retardant Coating". Joint Fire Research Organisation, F.R. Note 155/55.

3.2.4. The effects of moisture and chemical reactions

(a) Moisture content

Materials come to equilibrium with the moisture in the atmosphere. The amount they contain is normally expressed as a percentage by weight and is usually not considerable except for organic materials. The presence of water may affect the temperature rise in three ways. It will increase the thermal properties (capacity, density, conductivity); it will absorb latent heat in evaporation; and water vapour will diffuse from the hot to the cold portions, (Reference (1)). The resultant effect is often difficult to estimate. In general, the temperature rise of the front surface is reduced, whilst the temperature rise of the rear surface of loosely woven materials may actually increase, leading to burns (Reference (2)).

There is some controversy about the effect of moisture in such materials as concrete, bricks and asbestos cement; for instance, it has been suggested that water vapour might be the cause of spalling.

(b) Chemical reactions

Depending upon the type of material, various reactions may occur. At the high temperatures that may be attained, paints carbonise, wood blackens, common metals oxidise. These effects may change the thermal properties and the absorptivity. In addition, they may lead to the generation of heat.

/For

For organic materials such as wood, this is probably negligible below 500°C (References (3) and (4)). Estimates of damage suffered neglecting chemical heating will be conservative. Endothermic reactions having the reverse effect, can confer some protection.

References

(1) Solvarson, K. R. "Moisture in Transient Heat Flow". Heating, Piping and Air Conditioning, 1955, Vol. 27, pages 137-142.

(2) Simms, D. L., Hinkley, P. L., and Roberts, Valerie E. "The effect of water in clothing". Joint Fire Research Organisation S.R. Note No. 366/1958.

(3) Thomas, P. H. and Simms, D. L. "Thermal Damage Initiation by Radiation and Chemical Decomposition - Some Theoretical Aspects". Joint Fire Research Organization, F.R. Note No. 331/1957.

(4) Lawrence, E. K. "Analytical Study of Flame Initiation". M.Sc. Thesis, Department of Chemical Engineering, Massachusetts Institute of Technology, 1952.

3.2.5. Heat losses

(a) Heat loss from surface

Any hot body loses heat from its surface by radiation and convection. An expression for the heat loss (q) from the surface is -

$$q = \bar{e}\sigma(T^4 - T_o^4) + H'(T - T_o) \qquad (1)$$

where $\bar{e}\sigma(T^4 - T_o^4)$ represents the radiation loss according to the Stefan-Boltzmann law, with $\bar{e}$ the mean emissivity from the surface over the temperature range from T_o to T, and σ the Stefan-Boltzmann constant.

The convection loss is represented by the term $H'(T - T_o)$ where H' is the convective heat transfer coefficient.

For most calculations, it is sufficient to use the so-called Newtonian Cooling Law and choose the best value of H, the Newtonian cooling constant, for the temperature range used (Reference (1)), ie.

$$q = H(T - T_o) \qquad (2)$$

Heat losses by re-radiation and convective cooling may be neglected for small bombs (up to 20 KT), have only a marginal effect for medium size bombs (20-50 KT), but must be considered for bombs greater than 50 KT. This may be seen from Figures 2 and 3, and Figures 6 and 7, of Section 3.3.

(b) Heat loss to the interior

For short irradiation times, most materials may be considered to be semi-infinite solids. For thin materials, especially those that are good conductors, there may be some heat losses from the back surface. The effect is further considered in Section 3.3.

Reference

(1) Lawson, D. I., Fox, L. L. and Webster, C. T. "The Heating of Panels by Flue Pipes". Fire Research Special Report No. 1. H.M. Stationery Office, London, 1950.

3.3. Calculation of the temperature rise of an irradiated slab

It is assumed that:-

(a) the absorptivity of the surface is constant;

(b) the energy is absorbed at the surface;

(c) the material is dry and inert;

(d) the material is homogeneous.

The temperature rise θ, of a solid bounded by two parallel planes (a slab) of thickness 2l, losing heat from both faces by Newtonian cooling, and exposed on one face of absorptivity a to a constant intensity of radiation I, is obtained from:-

$$\frac{\partial^2\theta}{\partial x^2} = \frac{1}{k}\frac{\partial\theta}{\partial t} \qquad (t > 0) \qquad (1)$$

$$\frac{aI}{K} = h\theta + \frac{\partial\theta}{\partial x} \qquad (x = +l) \qquad (2)$$

$$h\theta = -\frac{\partial\theta}{\partial x} \qquad (x = -l) \qquad (3)$$

$$\theta = 0 \qquad (t = 0) \qquad (4)$$

where $h = \frac{H}{K}$

H is the Newtonian cooling constant

k is the thermal diffusivity $= K/\rho c$

K is the thermal conductivity

ρ is the density

c is the specific heat of the irradiated material

t is the irradiation time

x is the distance within the solid

The solution to these equations is complex (References (1) and (2)). However, within certain ranges of values of two dimensionless groups, the Fourier number kt/l^2, and the Biot number hl, useful approximations may be made. These are shown diagrammatically in Figure 1.

(i) The uniform slab

For the region A, in Figure 1, there are in effect no temperature gradiants within the solid. The mean temperature rise θ_M and the surface temperature rise θ_F are given by:-

$$\theta_F = \theta_M = I/2H \left(1 - e^{\frac{-Ht}{\rho c l}}\right) \qquad (5)$$

This is plotted in dimensionless form in Figure 2.

(ii) The non-uniform slab

For the regions A, B, C, D in Figure 1 there is a linear temperature gradient through the slab and the mean temperature is given by equation (5). The difference between the front surface temperature θ_F, and the mean temperature θ_M is given by:-

$$\theta_F - \theta_M = \frac{Ihl}{2H(1 + hl)} \tag{6}$$

Regions where $\frac{\theta_F - \theta_M}{\theta_M}$ is less than 25 and 50 per cent respectively are shown as B and C in Figure 1.

(iii) The transient case with a finite slab

No simple solution exists for this case. It is probably easiest to estimate the temperature rise by interpolation between case (ii) and case (iv).

(iv) The semi-infinite solid

For the region E in Figure 1 there is an insignificant rise in temperature of the rear surface and the temperature rise of the front surface is given by:-

$$\theta_F = \frac{I}{H}\,(1 - e^{\beta^2}.\ \mathrm{erfc}\beta) \tag{7}$$

where $$\beta = \frac{H}{K}\sqrt{kt} = h\sqrt{kt}$$

Equation (7) is shown plotted in dimensionless form in Figure 3.

The temperature rise within the solid is given by equation (8).

$$\theta = \frac{I}{H}\left[\mathrm{erfc}\frac{x}{2\sqrt{kt}} - e^{(hx + h^2kt)}\,\mathrm{erfc}\left(\frac{x}{2\sqrt{kt}} + h\sqrt{kt}\right)\right] \tag{8}$$

Solutions of equation (8) are given in Figure 5.

In order to estimate the temperature rise, it is necessary to obtain a value for the dimensionless groups, β or $\frac{Ht}{\rho cl}$ and hl. The thermal constants may be obtained from Table 4. (Section 3.2.2.) A value for H may be estimated from Figure 4, and the rise in temperature may then be read from Figure 2 or 3. If this temperature rise does not agree with the value used for choosing H, a more accurate value for H may be chosen to obtain a closer approximation to the temperature rise.

Varying impulses of radiation

The scaling laws obeyed by the pulse of radiation (given in Section 3.2.1) make the computation of temperature rise fairly straightforward for all sizes of explosion.

The surface temperature rise of a semi-infinite solid may be computed by an electrical analogue (Reference (3)) and is shown in Figure 6. An analytical solution for the mean temperature of a slab with a linear temperature gradient has been obtained (Reference (4)) and is shown in Figure 7.

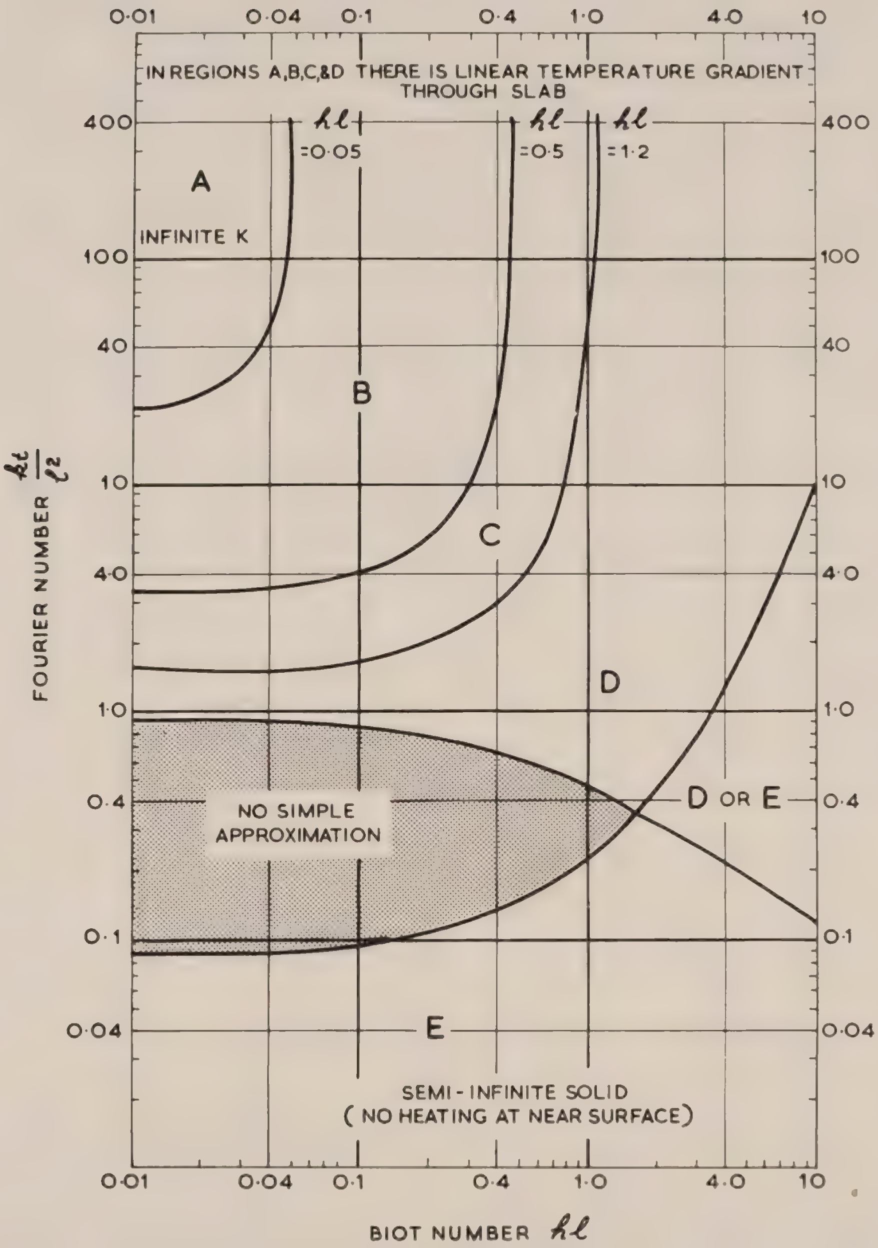
References

(1) Simms, D.. L. "The Correlation of Ignition Time with the Physical Properties of Materials, Part I. Spontaneous Ignition of Cellulosic Materials". Joint Fire Research Organization, F.R. Note No. 319/1957.

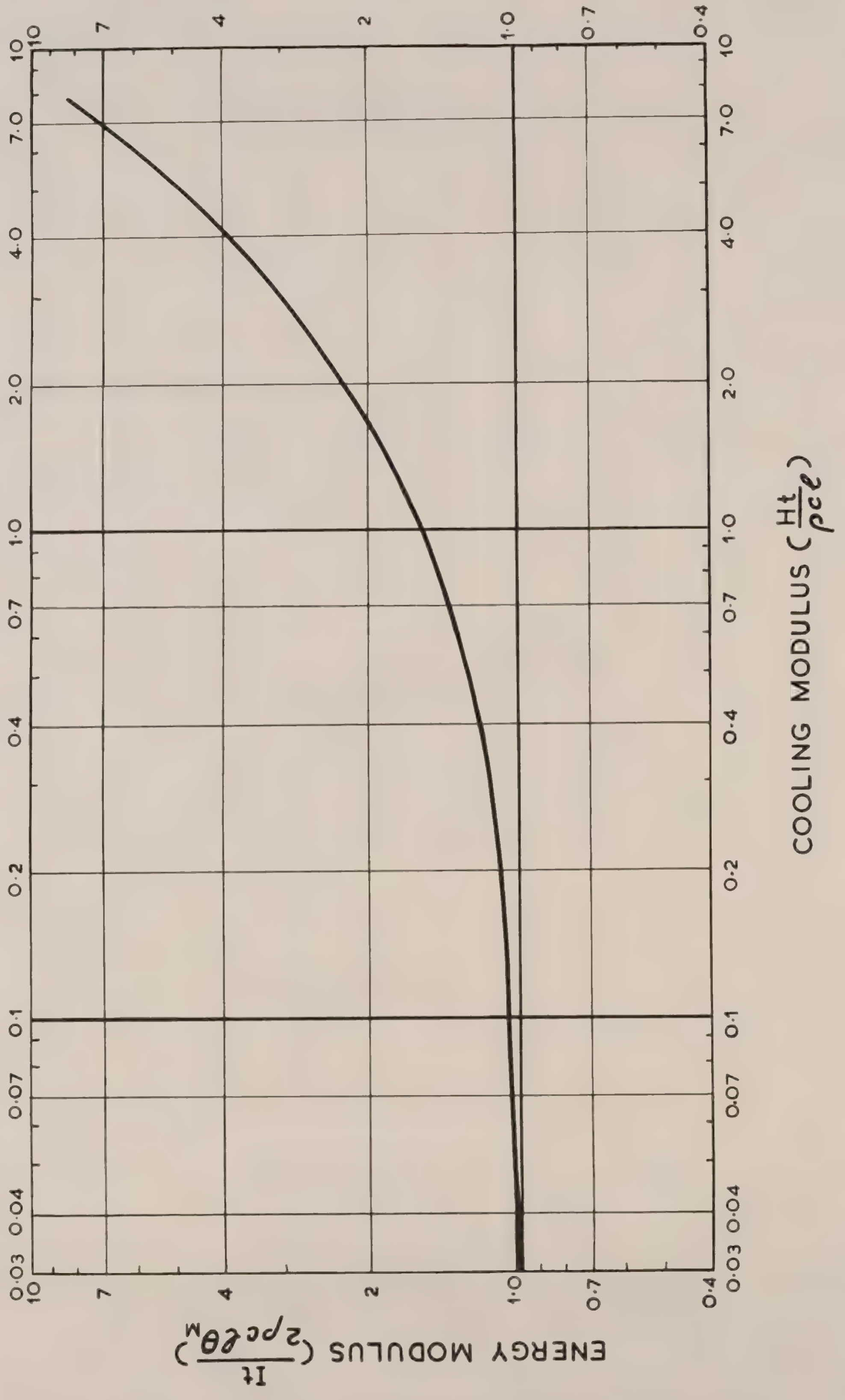
(2) Carslaw, H. S. and Jaeger, J. C., Conduction of Heat in Solids (O.U.P.).

(3) Lawson, D. I. and McGuire, J. H. "The Representation of Distributed Resistance and Shunt Capacitance Circuits by Lumped Networks". Joint Fire Research Organization, F.R. Note No. 196/1955.

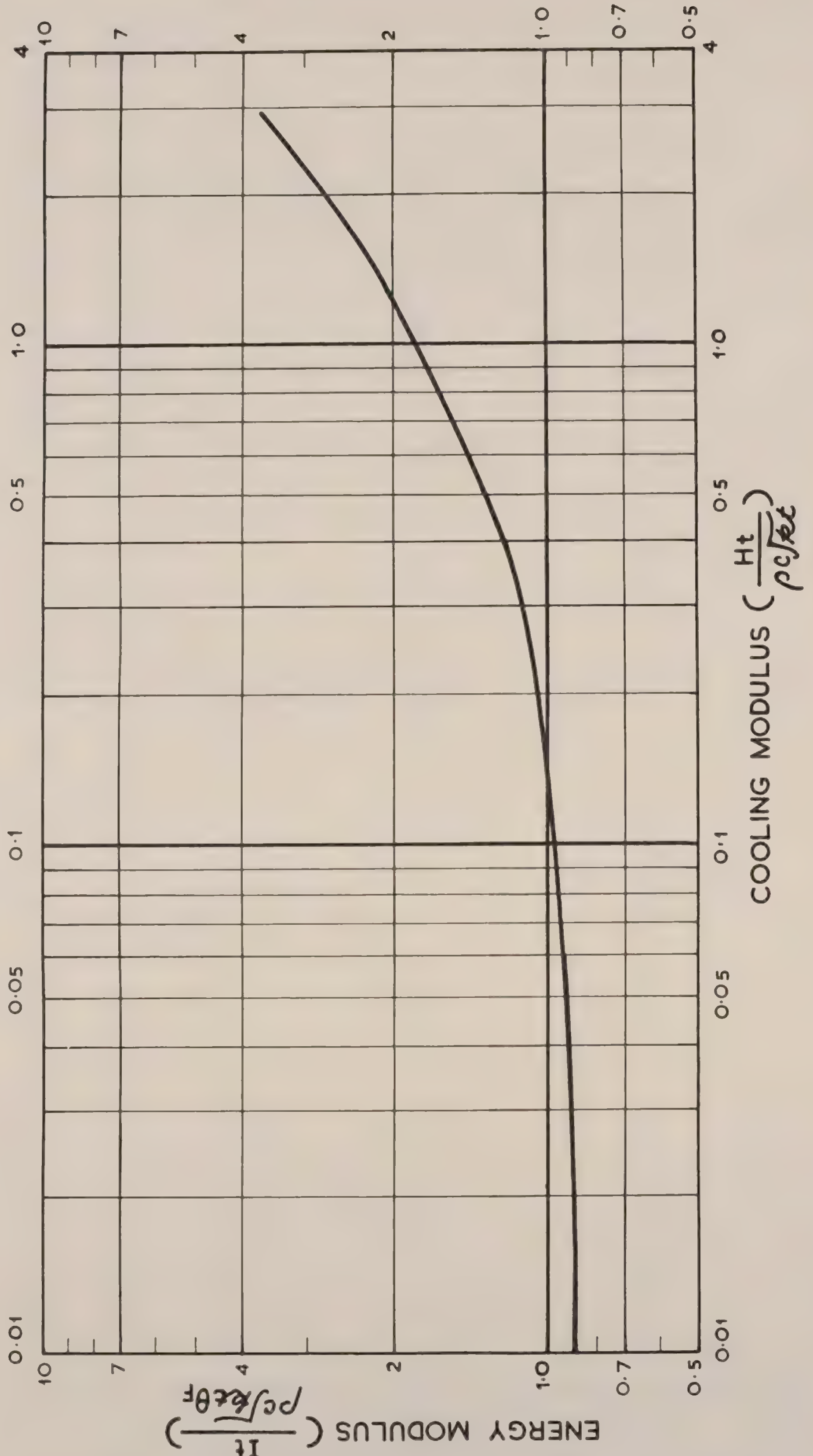
(4) Thomas, P. H., Simms, D. L., and Law, Margaret. "The correlation of the threshold for ignition by radiation with the physical properties of materials". Joint Fire Research Organisation, F.R. Note No. 381/1958.



ROLE OF DIMENSIONLESS GROUPS IN DETERMINING SURFACE TEMPERATURE RISE



THEORETICAL VALUE OF MEAN TEMPERATURE RISE
FOR A SLAB WITH LINEAR TEMPERATURE GRADIENT



THEORETICAL VALUE OF SURFACE TEMPERATURE RISE
OF AN IRRADIATED SEMI - INFINITE SOLID

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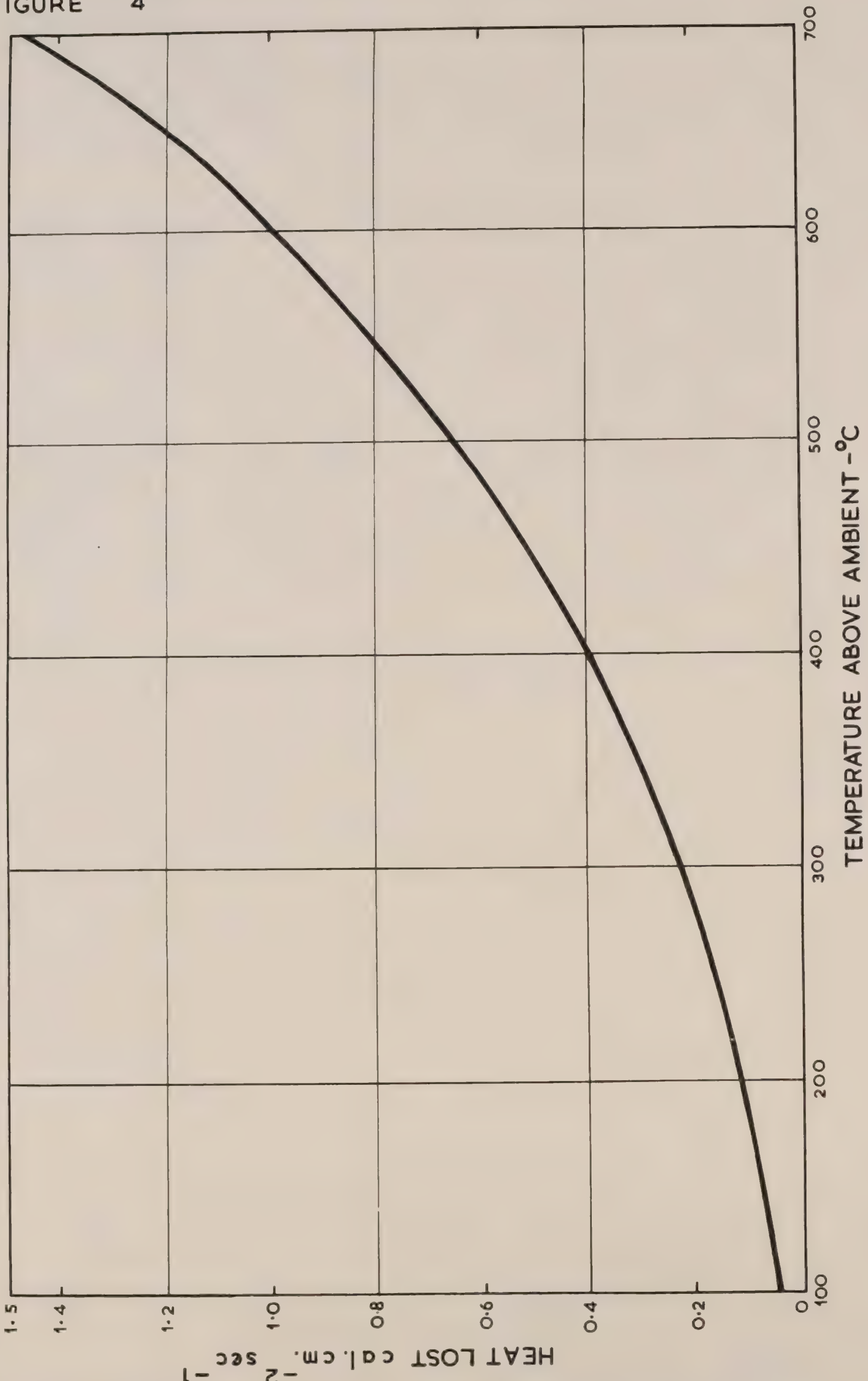

RADIATION AND CONVECTION LOSSES FROM A HOT BODY TO AN AMBIENT TEMPERATURE OF 17° C

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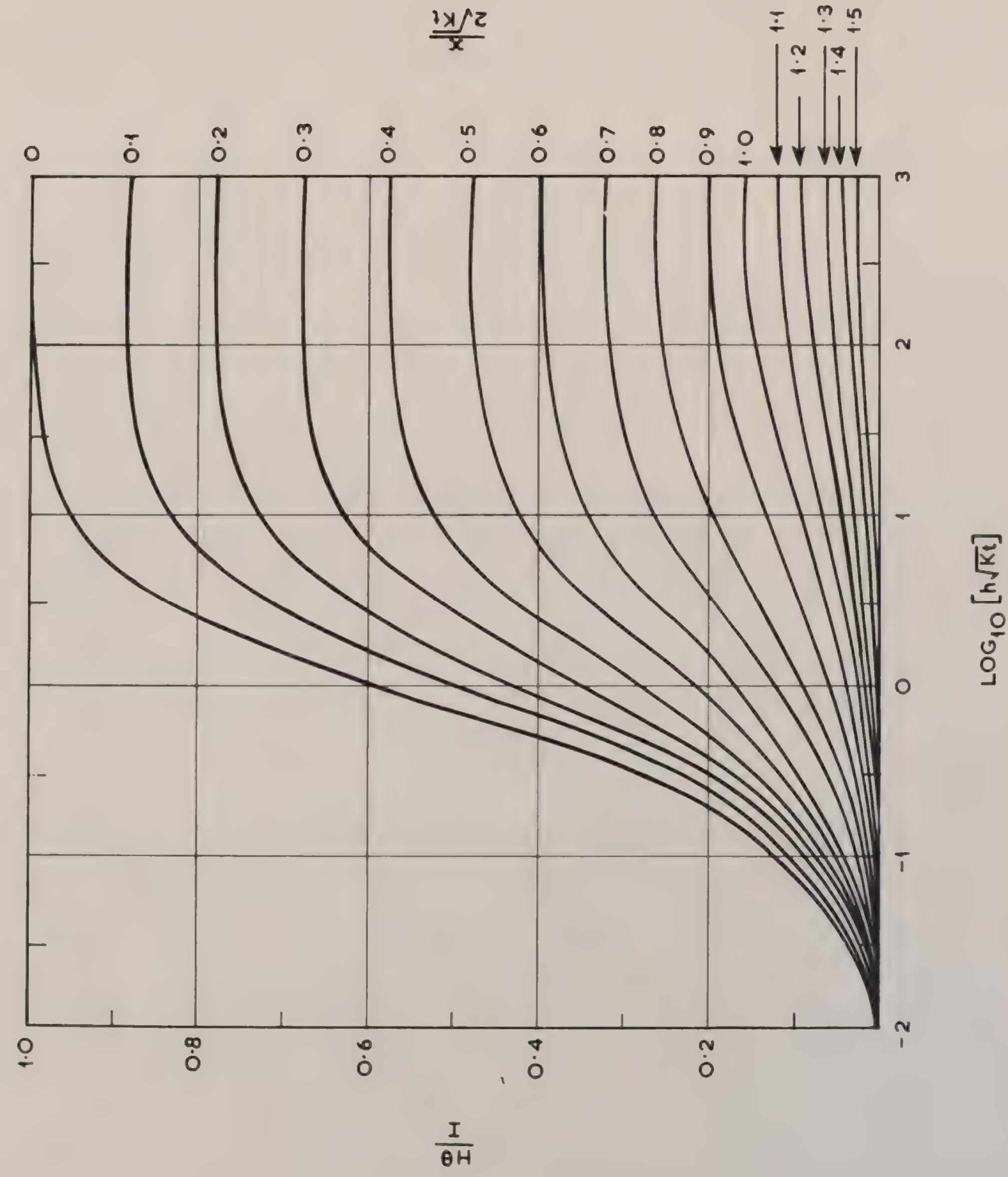
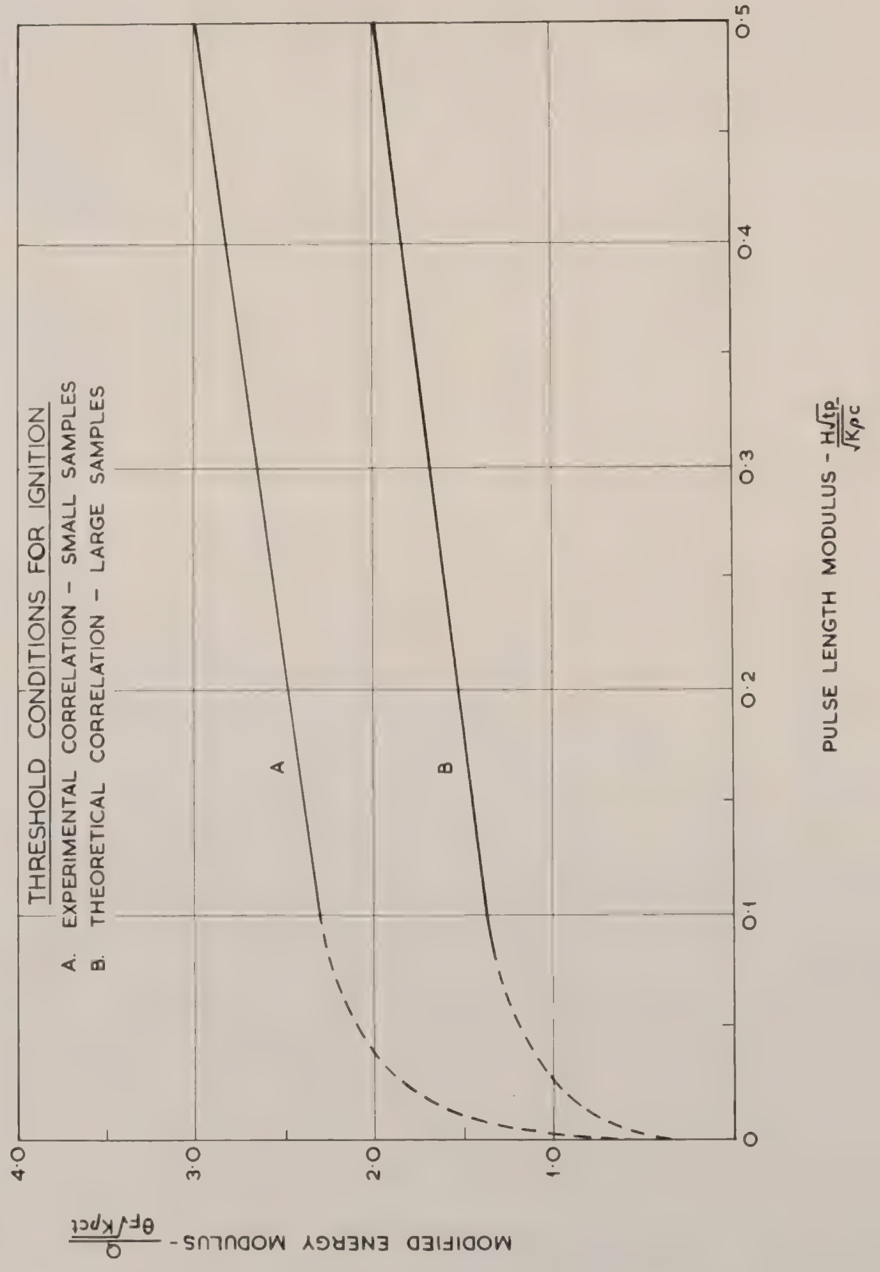
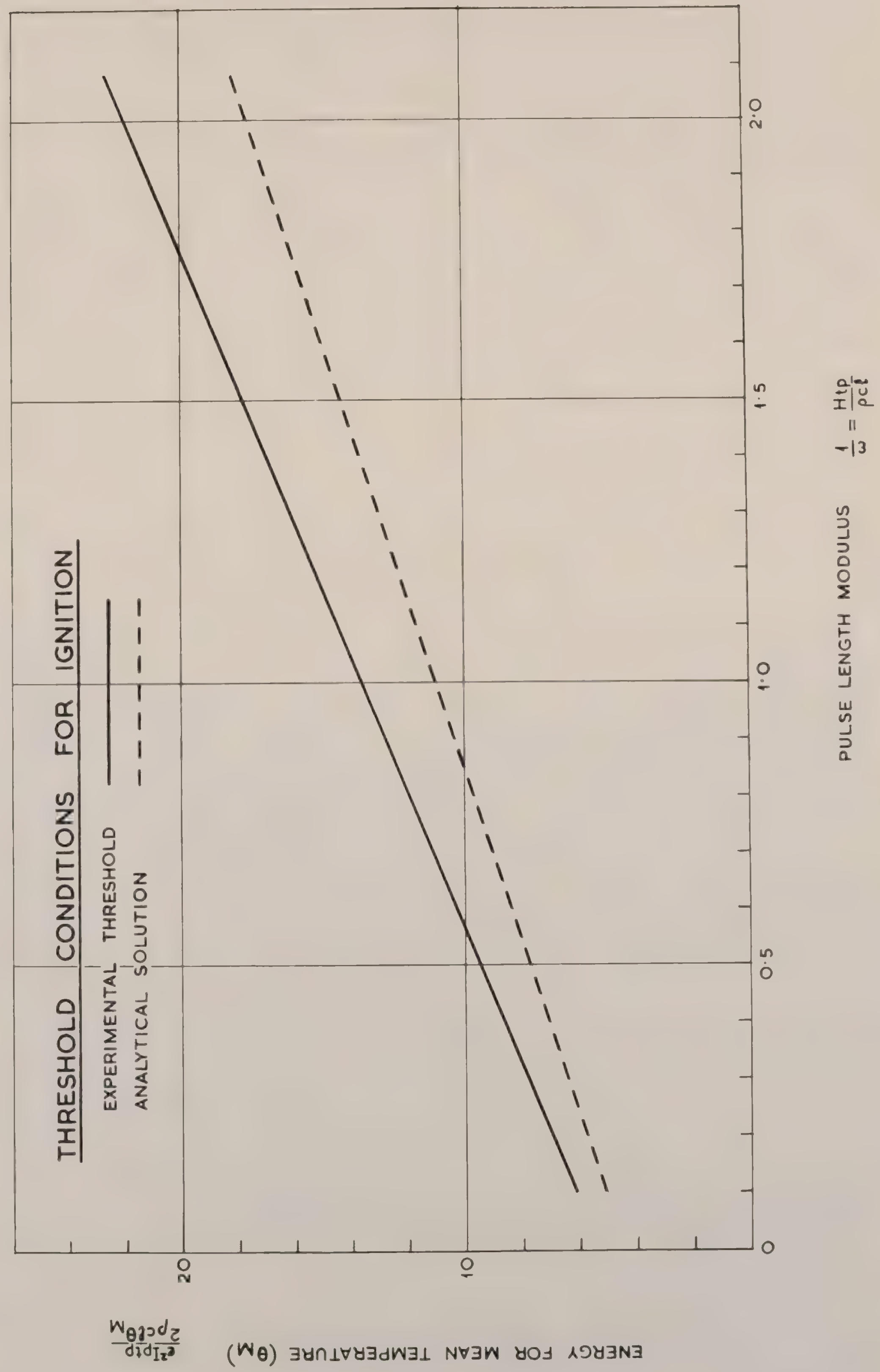


TEMPERATURE DISTRIBUTION IN THE SEMI-INFINITE SOLID WITH RADIATION AT ITS SURFACE



THE SURFACE TEMPERATURE RISE OF AN IRRADIATED SEMI-INFINITE SOLID



THE MEAN TEMPERATURE OF A SLAB
WITH LINEAR TEMPERATURE GRADIENT

CHAPTER 4 - THERMAL EFFECTS ON MATERIALS

Chapter 3 enables the effect of temperature-time patterns in irradiated materials to be estimated. Most materials are not inert and various kinds of thermal damage can occur, depending upon the rate and time of heating. Combustible materials may char, crack, melt, and ignite with a flame which may or may not persist. Non-combustible materials may melt, crack, shatter, or lose strength. It is not yet possible to give criteria for all these effects, but some available data are presented in this Chapter.

4.1. Thermal Damage to Combustible Materials

When radiation falls on the surface of a combustible material, the temperature at the surface and throughout the material rises in a way and at a rate depending upon the factors listed in Chapter 3.

In the surface region, the rise in temperature beyond 100°C is temporarily checked until the moisture has been driven off. In the common organic materials, mainly cellulose and its derivatives, a chemical reaction begins at about 180°C, scorching or charring the surface. This reaction may become extremely rapid at about 250°C. If the rate of heating is fast enough to produce volatiles, which form a flammable mixture with air, then the surface of the material bursts into flames, which may or may not persist. If a subsidiary ignition source is available, then a far lower rate of heating may be sufficient to cause ignition (Reference 1)). Many plastic materials, e.g. nylon, perspex, terylene, melt at about 200°C.

Thus, depending upon the time of exposure and the intensity of radiation, a given material may char, melt or ignite with or without persisting flame. Most of the work carried out in this country has been concerned with fire research and has therefore used radiation characteristic of a temperature of 1100°K (Reference (1)), but apparatus is now available (Reference (2)) to study the effects of using radiation of the quality of a nuclear explosion. A device for producing impulses of energy of shapes corresponding to any weapon yield, has also been developed.

The correlation of thermal damage - A method has been developed at the Fire Research Station for the correlation of thermal damage (References (3),(4),(5),(6),(7)). The temperature rise is calculated on the assumption that the material is thermally inert, and dimensionless groups are derived to express the thermal parameters (see Figure 6 of Section 3.3, Chapter 3). Satisfactory correlations between theoretically derived curves and threshold conditions for ignition have been obtained using an ignition temperature of 525°C (Reference (5)). Similarly, correlations between field and laboratory data for charring have been obtained using a charring temperature of 300°C (Reference (6)). Results from both British and U.S. field trials on the total destruction of fabrics have also been correlated, (Reference (7)), and are shown in Figure 1.

Similar techniques could be applied to assess thermal damage in other irradiation problems.

Estimates of the effect of moisture content on the ignition of wood have also been made (Reference (8)). The effect appears to be small for ignition by nuclear explosions (Reference (9)), though it may reduce the chance of a continuing fire being started.

A general survey of the problem is given in the publication "Fire and the Atomic Bomb" (Reference (10)).

References

(1) Lawson, D. I., and Simms, D. L. "The Ignition of Wood by Radiation". British Journal of Applied Physics, 1952. Vol. 3, pp. 288-292.

(2) Hinkley, P. L. "High Intensity Radiation from a Carbon Arc Ellipsoidal Mirror". Joint Fire Research Organisation. F.R. Note No. 270/1957. Ibid, Part II. "The Shape of the Pulse of Radiation". S.R. Note No. 29/1957. (Secret)

(3) Simms, D. L. "The Correlation of Ignition Time with the Physical Properties of Materials". Part I. "Spontaneous Ignition of Cellulosic Materials". J.F.R.O., F.R. Note No. 319/1957.

(4) Thomas, P. H., and Simms, D. L. "Thermal Damage to Solids by Radiation and Chemical Decomposition". J.F.R.O. F.R. Note No. 331/1958.

(5) Thomas, P. H., Simms, D. L. and Law, Margaret. "The correlation of the threshold for ignition by radiation with the physical properties of materials". J.F.R.O. F.R. Note No. 381/1958.

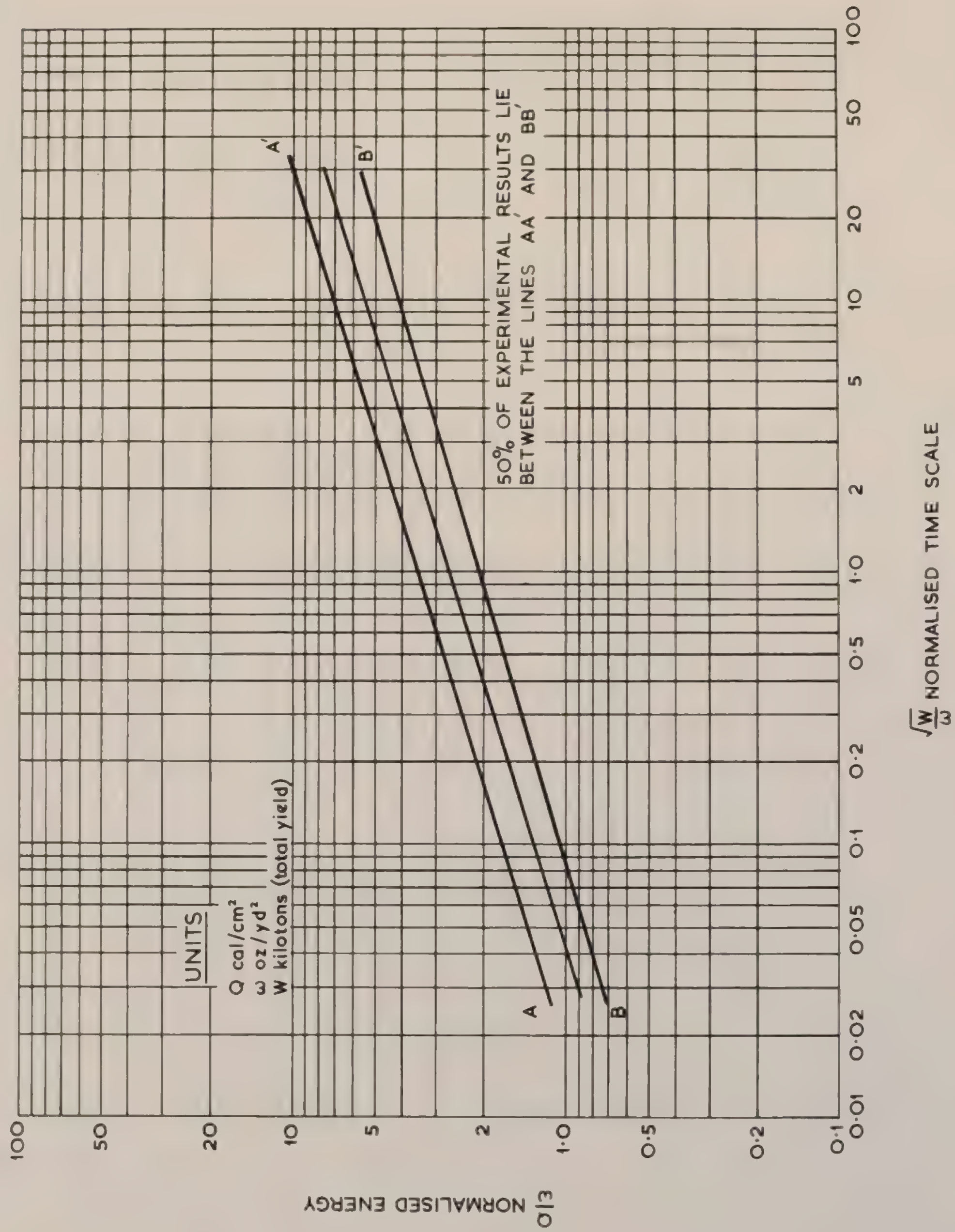
(6) McGuire, J. H., Smith, P. G., and Thomas, P. H., "Correlation of Field and Laboratory Tests on the Exposure of Fabrics to Radiation". J.F.R.O. S.R. Note No. 37/1958 (Secret)

(7) Thomas, P. H., and Simms, D. L., Correlation of field data for the total destruction of fabrics by nuclear explosions. J.F.R.O. S.R. Note No. 36/1958. (Confidential)

(8) Thomas, P. J., Simms, D. L., and Law, Margaret, "The Effect of Moisture Content on the Ignition of Materials by Radiation". J.F.R.O. F.R. Note No. 280/1956.

(9) Simms, D. L. and Law, Margaret. "The Effect of Moisture Content on the Ignition of Materials by an Atomic Explosion" J.F.R.O. S.R. Note No. 31/1957. (Restricted)

(10) Lawson, D. I. "Fire and the Atomic Bomb". Fire Research Bulletin No. 1, H. M. Stationery Office, 1954.



CORRELATION FOR TOTAL DESTRUCTION OF FABRICS
BY THERMAL RADIATION

4.2. Critical Energy Data for Combustible Materials

4.2.1. Textiles

Small specimens of various textiles were exposed at Operation Buffalo to the heat flash from Round I (about 15 KT), and the extent of the damage observed is summarised briefly in Table I, for a selection of the materials used. The following general conclusions are made in Reference (1) from consideration of the extensive thermal data obtained at Operation Buffalo.

(i) Materials which decompose without melting, or before melting begins (e.g. cotton, wool, etc.) afford better protection to the underlying skin that those that melt or are softened on exposure to heat (e.g. nylon, polyvinylchloride and synthetic fibres generally).

(ii) Resistance to damage by thermal radiation generally increases with increasing weight per unit area of the material, and several layers are much superior in this respect to a single layer of the same total weight.

(iii) White or light-coloured materials suffer less damage than dark materials, but thin white materials transmit the radiation to the underlying layers more readily than do dark-coloured materials. Thin white materials in contact with black underlying layers are damaged by heat sooner than when the underlayer is white.

(iv) In fabrics composed of a mixture of cotton and nylon there is an indication that resistance to damage is slightly reduced by the presence of nylon, owing to acceleration of the rate at which heat damage occurs.

(v) Terylene only improves the heat resistance of wool marginally.

(vi) Flameproofing does not affect the flashing of fabrics.

In Table 2 (taken from Reference (2)), the critical radiant exposures for specified damage to various fabrics are shown for three weapon yields. These values apply for an ambient relative humidity of 65% and an ambient temperature of 20°C. For extremely dry conditions the values shown for fabrics should be reduced by 20%. For extremely high relative humidity, near 100% at 20°C, the values for fabrics should be increased by 25%. If the fabrics are water soaked, the critical radiant exposures should be increased by 300%. It should be emphasized that the values in Table 2 for uniforms refer to damage to the material itself, and are not applicable for predicting skin burns under uniforms.

A correlation of these results is shown in Figure 1 of Section 4.1, from which the threshold conditions for damage to other materials may be estimated, (Reference (3)). White materials require about twice as much energy for total destruction as other materials. There does not appear to be any significant difference between different types of material, sizes of bomb, or origins of results.

References

(1) A.W.R.E. Report T12/58. Operation Buffalo Target Response Tests, Materials Group. Part 2: "Effects on Textiles". (Confidential)

(2) Capabilities of Atomic Weapons. U.S. Department of the Army. TM23-200 p.12-3 (Confidential)

(3) Thomas, P. H. and Simms, D. L., "Correlation of field data for total destruction of fabrics by nuclear explosions." Joint Fire Research Organisation". S.R. Note No. 36/1958. (Confidential)

TABLE I - Damage to Miscellaneous Textiles by Thermal Radiation from an Approximately 15 KT Weapon

Material	Thickness in.x 10^{-3}	Weight oz/yd^2	Calories/cm^2		
			Incipient damage	Serviceability just retained	Total Destruction
Cotton duck, water-proofed, olive drab	26	15	6	12	24
ditto, fireproofed	29	22.4	8	12	48
Cotton canvas, plain olive drab	37	24.1	3	16	32
ditto, waterproof	39	24.7	4	64	>128
Hessian, brown	64	12.4	4	8	32
" green	58	12.6	3	8	16
" black	63	13.1	4	6	16
100% wool, cavalry twill fawn	52	14.3	3	6	>48
15% nylon, flannel grey	22	6.6	3	3	12
50% nylon, flannel grey	20	5.3	2-3	2	12
100% nylon, plain weave fawn	20	7.2	8	8	16
100% wool twill, white	28	9.0	4	12	32
20% terylene wool twill white	25	8.6	12	24	32
60% " " "	22	7.8	12	16	24
100% terylene twill white	19	7.6	8	8	24
100% cotton plain cloth pale blue	10	5.1	8	16-24	32
32% nylon " "	10	5.1	12	16	24
Serge battledress, khaki	50	14.5	4	12	32
Sateen combat suit, olive drab	20	8.8	4	6	24
Drill, cotton, khaki	23	7.3	6	6	12

TABLE 2 - Critical Radiant Exposure Values for Various Fabrics
(S = Scorched, D = Destroyed)

Uniforms	Colour	Weight (oz/yd^2)	Damage	Critical Radiant Exposure cals/cm^2		
				1 KT	100 KT	10 MT
Army						
Cotton twill fatigue	Green	8	S	3	5	9
			D	8	14	25
Wool serge (winter service)	Olive Drab	9	S	3	6	10
			D	21	37	66
Wool flannel	Olive Drab	11	S	3	5	8
			D	20	40	70
Wool tropical worsted	Khaki	11	S	6	9	13
			D	13	20	30
Cotton twill shirt and trousers (summer)	Khaki	6	S	4	6	11
			D	18	31	56
Navy						
Cotton twill (working)	Khaki	8	S	3	5	8
			D	15	26	46
Cotton denim (dungaree)	Blue	9	Nap S	6	10	17
			D	7	13	23
Cotton chambray shirting (working)	Blue	3	S	3	6	11
			D	7	13	22
Cotton twill (white uniform)	White	8	S	4	8	14
			D	34	60	109
Wool, Melton (dress blues)	Blue	16	S	1	16	13
			D	9	18	28
Wool, Kersey (overcoat)	Blue	30	S	1	2	3
			D	37	65	110
Wool, serge (officer's uniform)	Blue	14	S	5	9	16
			D	11	21	37
Wool, tropical worsted (officers' uniform)	Khaki	11	S	5	9	16
			D	11	20	37
Vinyl resin, combined (rain)	Black	13	S	1	1	2
			D	5	6	8
Marine Corps						
Cotton poplin shirting	Olive Drab	6	S	3	6	10
			D	10	18	32
Wool elastique (winter)	Green	16	S	2	4	7
			D	25	45	80
		21	S	5	8	15
			D	30	54	95
Wool, Kersey (winter)	Green	16	S	2	3	6
			D	27	48	85
Wool, serge	Green	12	S	2	3	6
			D	16	28	50

TABLE 2 (Contd.)

Uniforms	Colour	Weight (oz/yd^2)	Damage	Critical Radiant Exposure cals/cm^2		
				1 KT	100 KT	10 MT
Air Force						
Cotton twill shirt	Khaki	5	S	6	10	19
(tropical)			D	9	15	27
Wool gabardine shirt	Grey	8	S	10	17	28
			D	14	22	37
Wool gabardine shirt	Blue	8	S	1	2	4
			D	8	14	25
Nylon - flying jacket	Olive	5	S	2	3	6
	Drab		D	7	13	23

4.2.2. Plastics

Small specimens of various plastics were exposed at a number of sites at Operation Buffalo to the heat flash from an approximately 15 KT explosion (Reference (1)). The types of materials used were:-

1. Polythene sheet, low and high pressure variety, normal, black, and irradiated (thickness 0.061-0.069 inch).

2. Polyvinylchloride sheet of varying colour and platiciser content (thickness 0.059-0.085 inch).

3. Nylon sheet of varying grade and colour (thickness 0.128-0.131 inch).

4. Phenolic mouldings and laminates with various fillers (thickness 0.060-0.121 inch).

5. Glass fibre resin laminates. Different resins. (Thickness 0.061-0.069 inch).

6. High impact polystyrene, varying colours and fillers (thickness 0.065-0.151 inch).

7. Polytetrafluorethylene (P.T.F.E.) (thickness 0.126 inch).

8. Polychlorotrifluorethylene (P.C.T.F.E.) (thickness 0.058 inch).

After exposure, the samples were examined visually and mechanical tests were carried out where possible. The tests employed were tensile strength and elongation at break, flexural strength in 3-point bending, shear strength and hardness. Full details of these plastics and the mechanical test results are given in Reference (1).

The results obtained are based on only one specimen exposed at each site. Some anomalies may therefore be expected in the results owing to the variability of the materials themselves and to damage which may have arisen due to the positioning. Nevertheless, there are definite trends in the results, and some general conclusions can be drawn.

(i) The plastic materials generally withstood the exposure conditions rather better than would have been expected from consideration of their stability when heated at low intensities for long periods. In the group of thermo-plastic materials, the relative performance of the high and low softening point polymers was comparable.

(ii) Colour affected the behaviour of the specimens. In general, the black materials embrittled at much lower calorie doses than the light-coloured samples. The effects on the natural polymers, normally off-white in colour, and of those formulations containing white pigment, were very similar.

(iii) In the case of phenolic mouldings and laminates, the type of filler influenced the results. The glass and asbestos-filled laminates were least affected. The silver-coloured high impact polystyrene (filled with aluminium powder) was more distorted than other polystyrene samples, but the fall in flexural strength was of the same order.

(iv) The materials least affected by the exposure were the fluorine containing polymers P.T.F.E. and P.C.T.F.E., and some of the glass-fibre resin laminates. These samples were only slightly marked at the maximum thermal flux of 128 cals/cm^2. The fire-resistant polyester glass-fibre laminates however, showed some surface deterioration in the range 32-48 cals/cm^2, and a drop in flexural strength of 30% at a dose of 96 cals/cm^2.

(v) For the majority of the materials the critical point for visual surface damage was in the range 12-24 cals/cm^2. At thermal fluxes below this level, slight changes in the surface texture such as bleaching, polishing, or delineation of the exposure area, were evident in many oases. By visual assessment, the materials could be rated according to the thermal flux at which marked surface deterioration first occurred. It is evident from the results of the mechanical tests however, that the damage was, in the main, confined to the surface, and that the bulk of the material was unaffected. This is understandable in view of the poor thermal conductivity of plastics in general.

Some American data from Reference (2), on the behaviour of certain plastics to thermal radiation from nuclear explosions, is given in Table I below.

TABLE I

Material	Damage	Critical Radiant Exposure calories/cm^2		
		1 KT	100 KT	10 MT
Laminated methyl methacrylate	Surface melts	73	120	230
U.S.A.F. window plastic ($\frac{1}{2}$ inch)	Bubbling	240	430	750
Vinylite (opaque) ($\frac{1}{8}$ inch thick)	(Dense smoking	3	4	6
	(Flaming	20	20	25

References

(1) A.W.R.E. Report T18/58. Operation Buffalo Target Response Tests, Materials Group, Part 3 : Effects on Plastics. (Confidential)

(2) Capabilities of Atomic Weapons. U.S. Department of the Army, TM 23-200, page 12-4. (Confidential)

4.2.3. Rubbers

Service and civilian respirator rubbers were exposed at Operation Totem, and the results are summarised in Table I (Reference (1).

TABLE I - Effects of Thermal Radiation on Respirator Rubbers

Material	Total Incident Thermal Energy, cal/cm^2				
	7	11	21	35	63
G.S. Respirator rubber (1.9 mm thick)	Not Exposed	Flashed, Surface-melted	Flashed and burned	Flashed and burned fiercely	Flashed and burned fiercely
Civilian Respirator rubber (0.9 mm thick)	Very slight melting on front surface	Flashed, Surface-melted	Flashed and burned	Flashed and burned fiercely	Flashed and burned fiercely

This trial demonstrated that the risk to the wearer of a Service respirator of being burned by heat conduction through the rubber, was slight, but that there was some danger of this happening with the civilian respirator. The eye-piece of the Service respirator transmitted about 60% of the incident radiation; consequently the eyes and the areas surrounding the eyes will be susceptible to serious burn injury from explosions occurring in front of the wearer, at ranges beyond those corresponding to significant respirator damage. (See Chapter 7, Sections 7.2 and 7.8).

At Operation Buffalo, specimens of various types of rubbers were exposed to the thermal flash from an approximately 15 KT weapon (Reference (2)). A comparison was made of the behaviour of four rubbers - natural, polychloroprene, butadiene acrylonitrile (nitrile) and butadiene isoprene (butyl).

Each rubber was represented by specimens in three colours - black, white, and olive drab. Specimens of heavy and light cotton fabrics proofed with natural rubber and neoprene compounds, were exposed in order to assess the behaviour of relatively thin coatings of rubber.

The most obvious effect of exposure on the four types of mechanical rubber was contamination by desert sand of the specimens at the sites nearest to ground zero. This was apparently the result of thermal softening of the surface of the rubber, to which sand adhered through the ensuing blast. The heaviest contamination occurred mainly at a thermal dose of 96 cals/cm^2, rapidly decreasing with lower doses, and not occurring at all doses of less than 6 cals/cm^2. The colour of the rubbers also affected the surface contamination, which decreased in the order black, olive drab, white.

Mechanical tests (tensile strength and elongation at break) were carried out on many of the exposed specimens, with the results summarised briefly below.

Natural Rubber - The effect of thermal dose was less noticeable with increasing carbon black loading, and at the highest loading (100 parts black per 100 parts rubber) there was no significant effect attributable to heat. In the white and olive drab samples the effect of thermal dose was very slight and was less in the case of olive drab than of white samples.

Polychloroprene Rubber - Elongation at break appeared to be little affected by thermal dose, but there was marked reduction of the tensile strength of the black specimens at thermal doses above 6 cals/cm^2. It was considered however, that all the samples would have been serviceable for reasonably long periods. There was no significant effect on any of the white samples, nor on the olive drab samples exposed to doses of 64 cals/cm^2 or less.

Nitrile Rubber - The effect of exposure on the elongation at break and tensile strength of the black nitrile rubbers was of little significance at thermal doses below 128 cals/cm^2, and although there was some reduction at this figure (the highest thermal dose) the results were still within specification limits. Anomalous results however, were obtained with the white and olive drab samples, the elongation at break and tensile strength improving with increasing thermal dose up to 32 cals/cm^2, followed by a very slight fall. It is considered that the white samples would have been unusable, but that the olive drab would be capable of very limited use.

Butyl Rubber - In no case was there any significant effect on the elongation at break. On tensile strength, there was a marked effect at thermal doses of 96 cals/cm^2 and above, but at doses lower than this the results showed hardly any significant change. It is considered that all the samples would still have been serviceable.

The general conclusion drawn from the examination and testing of specimens is that the nature of the polymer and the colour of the material are the two main factors which influence degradation. On a colour basis, the rubbers displayed increasing resistance to thermal radiation, from white through olive drab, to black, (i.e. black samples most resistant). Of the polymers exposed, natural rubber showed the best resistance, followed by butyl and polychloroprene, with nitrile rubbers as the most seriously affected.

References

(1) A.W.R.E. Report T77/54. Effects on Respirators Anti-Gas. (Confidential)

(2) A.W.R.E. Report T16/58. Operation Buffalo. Target Response Tests. Materials Group, Part 4 : Effects on Rubbers. (Confidential)

4.2.4. Packaging Materials

Small specimens of sheet packaging materials were exposed to the heat flash from an approximately 15 KT weapon at a number of sites at Operation Buffalo. Multi-wall and hessian sacks filled with sand, lengths of rope of various fibres, and thermal screens of ground sheets and camouflage nets, were exposed to both heat and blast at several sites. Full details of the results will be found in Reference (1), but a summary of the main conclusions is given below.

Sacks - Sacks made of laminates of Kraft and bitumen Kraft union showed increasing depth of damage with increasing heat dose. The outer laminates were almost completely destroyed before the inner laminates were seriously affected. This survival of the lower layers indicates the value of a thermal screen built up of inflammable sheets supported by thin air gaps, and is confirmed by the damage sustained by the uncovered sand-filled hessian sacks. None of the paper sacks was holed by the heat flash up to a dose of 24 cals/cm^2, while the hessian sacks had spilled contents at 16 cals/cm^2. Temperature indicators which were placed behind the specimens in the exposure frames, recorded no temperature rise above 80°C behind the Kraft laminates on any site, while the temperature rose to at least 100°C at the 8 calorie site, increasing to 170°C at 48 calories, behind the hessian with a cotton underlayer, and to 140°C and 190°C at the same sites behind a single hessian layer.

Tarpaulins - Tarpaulins gave excellent protection against heat to all sacks with which they were placed, on sites where blast did not cause additional damage, but tentage similarly placed, caused more damage through catching fire than resulted from the heat flash alone.

Fibre Boards - Carton board and corrugated board showed the value of air-spaced laminates in a manner similar to that shown by the sacking. The building paper Sisalkraft and polymer transparent sheets showed a resistance to heat damage consistent with their construction, but the value of a metal foil coating in protecting paper from heat damage was very striking.

Timbers - There was no difference in the degree of burning shown by planed and unplaned samples of the same wood. The hard woods were slightly more sensitive to incipient scorching (at 8-12 cals/cm^2) than the soft woods, but were less deeply charred at the higher heat doses (up to 128 cals/cm^2).

Spray-Packaging Materials - A skin made solely from the vinyl plastics used for short-term packaging, suffered complete destruction at only 6 cals/cm^2, while the vinyl/bitumen skin with aluminium paint used for full protection suffered only surface damage up to at least 64 cals/cm^2, after which the specimens were torn by blast.

Ropes - The sisal ropes, both untreated and rot-proofed, showed some scorching after 8-12 cals/cm^2, but did not materially lose strength until the thermal dose exceeded 24 cals/cm^2, when the breaking loads showed an erratic loss of strength of about 20% to 30%, probably due to blast rather than heat. The terylene and nylon ropes showed no damage at thermal doses below 12 cals/cm^2. At higher doses, there was a proportional increase in loss of strength up to 50% at about 100 cals/cm^2, with corresponding signs of fusing of the polymer fibres.

References

(1) A.W.R.E. Report No. T29/58 Operation Buffalo Target Response Tests. Materials Group, Part 7. "Effects on Packaging Materials". (Confidential)

4.2.5. Paints

Samples of paints of formulations selected for heat resistance were applied to small plates of various metals, and exposed to the heat flash from a weapon of about 15 KT at Operation Buffalo. (Reference (1)).

Paint films applied to steel plates had the following formulations:-

(a) 1 coat green. Epoxide resin araldite 985E

(b) 1 coat aluminium. Epoxide resin araldite 985E

(c) 1 coat primer. Zinc pigmented butyl titanate
1 top coat. Aluminium pigmented butyl titanate.

(d) 1 coat green. Silicone resin.

(e) 1 coat aluminium. Silicone resin.

(f) 1 coat green. Silicone alkyd.

(g) 1 coat aluminium. Silicone alkyd.

(h) 1 coat primer DEF 1035
1 coat undercoat DEF 1044
1 top coat DEF 1044 green

(j) 1 coat primer DEF 1035
1 coat undercoat DEF 1044
1 top coat DEF 1044 type alkyd medium, aluminium

(k) 1 coat aluminium paint to CS 1199.

(l) 1 coat "Alifuse". Zinc/aluminium pigmented butyl titanate

No change in the paint layers was visible on specimens receiving heat doses up to 12 cals/cm^2. Some of the specimens on the sites nearest the ground zero were scattered by blast and not recovered. The remainder of the specimens showed the effects described in Table 1 below.

TABLE I

Thermal Damage to Paints on Steel Plates

Paint	Incident Thermal Dose (Cals/cm^2)						
	16	24	32	48	64	96	128
a. Epoxide Green	NC	NC	NC	Sl.loss	-	-	-
b. Epoxide	NC	Sl.Dc.	Sl.Dc.	Sl.Dc.	Marked Dc.	Marked Dc.	Film mechanically damaged.
c. But. Titanate 2 coats	NC	V.sl. Dc.	Sl.Dc.	Marked Dc.	Marked Dc.	-	Heavy Dc.
d. Silicone Resin Green	NC	NC	NC	Sl.Dc.	Sl.colour change Blistered	Marked darkng. Blistered	Film almost completely destroyed
e. Silicone Resin Aluminium	NC	NC	V.Sl. Dc.	Marked Dc.	Marked Dc.	Marked Dc. Pitted	Marked Dc. Pitted
f. Silicone Alkyd Green	NC	NC	NC	Darkng sl. blistering	As 48	As 48	As 48 Brown stain
g. Silicone Alkyd Aluminium	NC	NC	V.Sl. Dc.	Sl.Dc. some pitting	Marked Dc. some pitting	As 64	As 64
h. DEF 1044 Green	V.sl. darkng.	Sl. darkng.	Severe darkng.	Blackened	Blackened Erosion	-	Dark grey Erosion
j. DEF 1044 Aluminium	NC	NC	V.sl. Dc.	Marked Dc.	Marked Dc. some pitting	-	Marked Dc. Some pitting
k. CS 1199 Aluminium	NC	V.sl. Dc.	V.sl. Dc.	-	Sl.Dc. pitting	As 64	As 64
l. "Alifuse"	V.sl. Dc.	NC	V.sl. Dc.	Marked Dc. Pitting	Sl. Dc. pitting	As 64	As 64

NC = No change
Dc = Discolouration
V = Very
Sl = Slight

None of the paints listed in Table 1 showed any effect from heat doses below 16 cals/cm^2. Results at higher doses indicated that:-

1. A paint pigmented with aluminium is more resistant to heat flash than one with a green pigment.

2. Of all the paints exposed, those based on butyl titanate show greatest resistance to heat flash.

3. In comparing paints made from epoxide "araldite" resin, silicone resin, and silicone alkyd, the epoxide resin paints showed greatest resistance to heat flash.

In an additional series of tests at Operation Buffalo, specimens of paints applied to magnesium, titanium, steel and aluminium alloy plates were exposed to thermal flash of various intensities from a 15 KT explosion. Strips of heat-sensitive paints were applied to the backs of the plates to record the maximum temperature reached. Most of the specimens were samples of standard aircraft paint schemes. There were also some unpainted samples of polished metals, including silver plated steel and electro-polished aluminium ("Brytal"). Many of the plates located on sites receiving 96 and 64 cals/cm^2 were blown away, and those reamining were badly damaged by sand blasting. This prevented any precise appraisal of thermal damage, but generally the white paints were unaffected, whereas silver paints (i.e. aluminium pigments) showed obvious blistering. From sites receiving 48 and 32 cals/cm^2, the white and silver paints did not show any thermal damage, as the dose was insufficient to affect them. However, the brown-painted samples from these sites were severely burned.

References

(1) A.W.R.E. Report T27/58. Operation Buffalo Target Response Tests, Materials Group. Part 5 : Effects on Paints. (Confidential)

4.3 Absorption of Heat by Metallic Surfaces

The procedure for estimating the thermal dose to a surface is given in Section 1.3 of Chapter 1, and a discussion of the factors which influence the temperature rise of irradiated materials is given in Chapter 3. Some values of the temperature rise of irradiated surfaces have been obtained (References (3)).

Absorption data for sunlight and carbon arc radiation are presented in the following sections. The figures give a good general picture of what the initial absorption of fireball radiation is likely to be, but they should not be used for refined calculations. In particular, they do not indicate any change of absorption coefficient with dose absorbed. Ideally, we require relationships between the total incident does and total dose absorbed for each surface. As such data are not yet available, the present data are provided as an interim measure.

4.3.1. Absorption by Bare Metallic Surfaces

The absorptivity of a polished metal surface will be increased by roughening, and by dirt or corrosion. The influence of the state of the surface (polished or rough, oxidised or machined, etc.) can be seen from Table 1 below, which is taken from Reference (1). Whereas a trace of oxide (tarnishing) does not appreciably change the absorptivity, thick oxide layers raise it considerably. Heavily oxidised and very rough surfaces approach the behaviour of a black body. The values given in Table 1 may hold up to 200°C. For higher temperatures, too, they will not change much.

Table 1

Influence of the State of Surface of Metals upon the Absorptivity at 25°C

Substance	State of Surface	Percent Absorptivity
Copper	Polished	3
	Polished, slightly tarnished	3.5
	Shaved	7
	Oxidised black	78
Brass	Polished	4
	Polished, slightly tarnished	4.5
	After rolling	6
	Fresh rubbed with abrasive	20.5
Tin	Iron sheet, tinned	5.5
	Iron sheet, nickel plated, polished	4.5
	Iron sheet, nickel plated, dull	11
Zinc	Iron sheet, zinc plated, bright	24
	Iron sheet, zinc plated, grey	27.5
Iron	Sheet, newly treated with abrasive	24
	Cast, newly machined	43.5
	Sheet, stained	65
	Steel sheet, with skin due to rolling	66
	Steel sheet, with rough or brilliant oxide layer	81
	Cast, with smooth or rough cast skin	81

Some data on the absorption of radiant heat by metal surfaces, derived in part from Reference (2) are given in Table 2.

Some additional data on the absorptivities of steel, copper and aluminium for different wavelengths of thermal radiation are given in Table 1 of Section 3.2.2, Chapter 3.

References

(1) "Heat Transfer" M. Jakob, Vol.I p.126 (John Wiley, 1949)

(2) "The Calculation of Heat Transmission". M. Fishenden and O. A. Saunders, (H.M.S.O. 1932)

(3) Smith P. G., "Temperature Gradients in Painted and Unpainted Metals Subject to High Intensity Thermal Radiation Pulses". Joint Fire Research Organisation - S.R. Note No. 32/1957 (Confidential)

TABLE 2

ABSORPTION OF RADIANT HEAT BY METAL SURFACES

Metal	Percentage Absorption of Radiation from		
	Sun	Carbon arc Note (i)	Fireball (Note (ii)
Aluminium, superpurity electro-polished			14
Aluminium, pure, mechanically polished		11	
Duralumin	53		
Chromium plate	49		
Copper, mechanically polished			
Speculum metal, mechanically polished	39		
Gold, polished			
Iron, pure, polished	45		
Steel, polished	45		
Stainless steel			
Red Oxide of Iron	74		
Nickel, electrolytic	40	33	
Monel metal	43		
Platinum, pure	50		
Platinum, black	97		
Silver, polished	11	22	8
Tin		25	
Titanium		56	
Zinc, polished	46	48	

Note:- (i) These figures are probably too low as the metallic reflector to the arc removes near-ultra-violet radiation strongly absorbed by some polished metals, notably Al, Ag, Cr.

(ii) Preliminary calculation for a fireball at 6500°K.

4.3.2. Absorption by Painted Metal Surfaces

(a) Effect of pigment colour

The colour of the pigment will largely determine the degree of absorption, and values for a number of pigments are given in Table I for Solar Radiation (Reference (1))

Table 1

Absorption of Radiant Heat by Pigments

Colour	Material	Percent absorption of radiation from the sun
Black	Soot	99
Blue	Cobalt oxide	97
Green	Chromic oxide	73
Yellow	Lead chromate	30
Yellow	Lead oxide (PbO)	48
Red	Iron oxide	74
White	Alumina	16
White	Lead carbonate	12
White	Magnesia	14
White	Magnesium carbonate	15
White	Thoria	14
White	Zinc oxide	18

(b) Effect of the nature of pigment in white paint

A white pigment is a powder form of a transparent material which reflects a high total proportion of incident radiation by successive small reflections. As many paint media absorb radiation in the invisible portions of the spectrum, it follows that the reflective efficiency of a white paint depends to a considerable extent on the capacity of each pigment particle to reflect a high proportion of the radiation and thus limit the length of path of the radiation through the paint. The reflection coefficient of a pigment/medium interface is given by:-

$$\text{Reflection coefficient} = \frac{(\mu_p - \mu_m)^2}{(\mu_p + \mu_m)^2}$$

where μ_p is the refractive index of the pigment

and μ_m that of the medium.

The refractive indices of common white pigments are listed in Table 2 below.

Table 2

Pigment	Refractive Index
Silica	1.55
China clay	1.56
Whiting, calcium carbonare	1.58
Anhydrite, calcium sulphate	1.59
Mica	1.59
Talc	1.59
Blanc fixe, barium sulphate	1.63
Magnesium carbonate	1.64
White lead	2.0
Zinc oxide	2.0
Zinc sulphide	2.37
Titania, anatase	2.5
Titania, rutile	2.75

The refractive indices of paint media lie generally between 1.5 and 1.6. Slight increases occur during weathering.

In the commoner types of paint media, only those white pigments with refractive indices of two or more are efficient reflectors. Air voids greatly improve the reflectivity of a pigment, for at pigment/void interfaces $\mu_m = 1.0$. Whitewash and some distempers fall into this class.

The results of an investigation (Reference (2)) on paints are given in Table 3. The carbon arc absorption figures for the aluminium pigmented paints in this Table are probably too low, since the metallic reflector to the arc removes near ultra violet radiation. The following conclusions may be drawn from Table 3:-

(i) The absorptivity of finishes pigmented with rutile titania is about 25 to 30%. With multiple finishing coats, the figure can be reduced to near 20%, but at the expense of heat stability.

(ii) Nitro cellulose media tend to break down at relatively low temperatures, and to do so by rapid charring.

(iii) Stoving paints are more stable to heat than air-drying paints. The blistering of air-drying paints may be associated with solvent retention, especially where multiple coats have been applied. It is probable that a light stoving would increase the thermal stability of air-drying schemes.

American work on white paints (Reference (3)), has given the following results:

(i) Rutile titania was more reflective than anatase.

(ii) Silicone/alkyd media gave the greatest thermal stability.

(iii) Reflectivity increased markedly with increasing pigment/volume concentration.

(iv) Reflectivity increased with increase in the total thickness of the coating, 6 mils (0.006") being superior to 4 mils, which were, in turn, superior to 2 mils. There was no advantage in thicknesses greater than 6 mils.

(v) Reflectivity was increased by replacing part of the rutile titania by zinc oxide or china clay.

(vi) In schemes of total thickness of 2 mils, the colour of the primer had some effect, as whitening of the zinc chrome primer by addition of titania and china clay improved the reflectivity. It is not known whether the colour of the primer has any influence when it is covered by multiple finishing coats.

The reflectivities of rutile pigmented white cellulose and synthetic paint schemes (D.T.D.899A and D.T.D.827) for aircraft have been determined over the wavelength range 0.32 to 2.2 microns (Reference (4)). These schemes consist of varying weights of finish coats over a selection of filler type undercoats. The results indicate that the absorption of thermal energy occurs mainly in the rutile pigment. It is concluded that further improvement in reflectivity is unlikely whilst rutile is used as the sole pigment. However reflection of the energy in the ultra-violet (less than 0.4 micron) by a surface layer with no absorption of the energy in the visible and infra-red could increase the overall efficiency of the scheme to a nominal 95 per cent. The tests show that for these types of paint any increase in weight of the finish coat above 4 oz/yd^2 will not materially increase their reflective efficiency for radiation from a black body at 6000°K.

(c) Selection of paints

A single coat of paint applied by normal brushing or spraying technique weighs when dry, about 1 oz. per sq. yard, and has a thickness of about 1 mil. In calculating the temperature rise of painted metal, it should be assumed that the absorption figures quoted in Table 3 already include the effect of heat insulation due to the poor heat conductivity of the paint film.

The best paints for protection against heat flash consist of heat resistant media pigmented with titania and other white pigments which have absorptions of the order of 20 to 25%. It is hoped that current research will reduce this figure to about 17.5%. See also Reference (7).

It may be assumed that the absorption will rise rapidly as the paint scorches, reaching a figure of 60 to 90% when the paint chars.

Colours can be divided into two classes. For dark colours thermal stability is only of importance in so far as it is required to maintain the paint as protection against corrosion; charring will only raise the percentage of absorption of heat from a high value to a higher one. For colours of medium reflectance however, thermal stability of the paint is very important, for total heat absorption of a moderate absorber stable to high temperature could be less than that of a low absorber which breaks down at relatively low temperatures to become a high absorber. Some flame retardant treatments are mentioned in Chapter 6, Section 6.3 (iv).

(d) Skin temperature rise in aircraft

The skin temperature rise in an aircraft exposed to thermal radiation from a nuclear explosion is discussed in Reference (5). It is shown that in many situations aerodynamic cooling substantially reduces the temperature rise in thin skins of aircraft exposed in flight to thermal radiation from nuclear explosions. The maximum acceptable thermal dose, where this is determined by skin temperature rise, depends upon the time scale of the thermal input, and this upon the yield of the weapon involved.

In Reference (5) the problem is attacked by a finite difference analysis, and the maximum temperature rise and the time at which it occurs are shown to depend on a single non-dimensional parameter. The results are presented for a range of this parameter corresponding to the majority of practical situations.

The effects of non-uniform absorptivity of thermal radiation on the temperature rise in aircraft skin (e.g. under insignia) have been examined and are reported in Reference (6). Some recent tests of heating under load are reported in Reference (7).

References

(1) "The Caluclation of Heat Transmission". M. Fishenden and O. A. Saunders. (H.M.S.O. 1932).

(2) R.A.E. Farnborough (Chemistry Dept.) Unpublished Work.

(3) Vita-Var Corporation "Investigation of Protective Coatings to Decrease Vulnerability of Aircraft to Thermal Radiation". 1st, 2nd and 3rd quarterly reports (1954/55) (Confidential/Discreet) T.I.L. Nos. P.55101/2/3.

(4) R.A.E. Tech. Note Chem. 1323 (November, 1957) The Reflectivities of Rutile Pigmented White Paint Schemes for Aircraft over the Wavelengths 0.32 to 2.2 microns (Restricted)

(5) R.A.E. Tech. Note Mech.Eng. 251 (March, 1958) - Skin Temperature rise in an Aircraft exposed to Thermal Radiation (Confidential)

(6) R.A.E. Tech. Note Mech.Eng.268 (July, 1958) - The Effects of Non-Uniform Absorptivity of Thermal Radiation from Nuclear Explosions on the Temperature Rise in an Aircraft Skin. (Confidential)

(7) R.A.E. Test Note Structures 1519. July, 1958. Combined Transient Heating and Static Loading Test of a Valiant Aileron. (Confidential)

TABLE 3

ABSORPTION BY REPRESENTATIVE PAINT SCHEMES ON METAL SURFACES

Paint Scheme	Primer	Filler	Finish	Pigment in finish	Percent Absorption of radiation	Onset of deterioration in arc, °C
					Carbon arc	
Nitrocellulose finish						
DTD.766A	Etch	None	Alhyd.N/C	Pol.Al.flake	39	200 S
DTD.722	Alkyd.X2	None	Alkyd N/C	Rut.TiO_2	35	150 Bl.C
DTD.722 Finish polish	Alkyd.X2	None	Alkyd.N/C	Rut.TiO_2	35	150 Bl.C
DTD.754	Etch	None	N/C	TiO_2+ SiO_2	30	230 S
Air Drying Alkyd						
Mat. DTD.314	Etch	None	Alkyd	TiO_2 + SiO_2	26	250 S
Glossy DTD.827	Etch	Alkyd + China clay	Alkyd	Special I.R. reflectors	54	200 Bl.S
"	"	"	"	Al, non-leafing	42	200 Bl.S
"	"	"	"	Al, leafing	40	200 Bl.
"	"	"	"	Al.polished	34	180 Bl.C
"	"	"	"	TiO_2	27	170 S
"	"	"	"	TiO_2 + SiO_2	27	180 Bl.S
"	"	"	Alkyd - 3 coats	TiO_2	22	150 Bl.S
Stoving Alkyd U/F						
DTD.235	Alkyd	None	Alkyd U/F	TiO_2 + SiO_2	30	250
Epoxy, cold catalysed						
DTD.900/4414	Epoxy	None	Epoxy	TiO_2	27	230 S
Epoxy, stoving						
-	Epoxy	None	Epoxy P/F	TiO_2	35	230 S
Silicone Air drying						
Mod. of DTD. 900/4381	None	None	Silicone	White	30	200 S
"	Etch	None	Silicone	White	35	200 S
Silicone stoving						
-	Silicone	None	Silicone	Pol.Al.flake	37	250
-	Silicone	None	Silicone	TiO_2	24	250
Butyl titanate						
-	Bu.tit.	None	Bu.tit.	Pol.Al.flake	24	250

Notes: Carbon arc. Radiation flux 4 cals/cm^2 per sec. giving a test panel temperature rise of rise of 13°C per sec.

N/C = Nitrocellulose
Pol.Al.flake = Polished aluminium flake pigment
U/F = Ureaformaldehyde
P/F = Phenol formaldehyde
Etch = Etch Primer, DTD.868
I.R. = Infra-red
S. = Scorching to a yellow colour
Bl. = Blistering
C. = Charring

4.4. The Mechanical Properties of Metals Heated for Short Periods

4.4.1. Introduction

In general the strength of metal falls with the rise of temperature. Over a range of 200°C, however, the fall may be modified and in the case of lowly alloyed steels even reversed, by an effect known as strain ageing or strain hardening, attributed to an incipient precipitation of impurity atoms within the crystal lattice impeding further slip. The temperature range over which this phenomenon occurs in steel is 200-400°C. Heat treatable alloys which rely for their strength on the formation or incipient precipitation of a metastable phase may lose both strength at temperature and residual room temperature strength rapidly when temperatures are reached at which local or metallurgical changes of structure occur quickly. With heat treatable aluminium alloys, these permanent changes occur at 200-250°C, depending on the type of alloy. The elastic stiffness (Youngs Modulus E) which is a property of each individual metal, and is substantially independent of the presence of alloying elements, falls steadily with rise of temperature. Recovery at room temperature is normally complete, if no changes of state have occurred.

The extent of thermal damage will depend both on the temperature and the time for which it is maintained. Very few results are available for brief heating, but an estimate of the effects may be based upon data for extended heat treatment. In most cases available data refer to room temperature measurements following heat treatment, but in some cases actual properties at the elevated temperatures are given. In many cases of military interest, it will be the actual time history of the strength of the material during heating that will be important. There are no such data available at present.

Sections 4.4.2. - 4.4.6. present typical data for the following properties:

(i) Tensile strength at temperature. In the case of unstable alloys which undergo permanent metallurgical changes at relatively low temperatures, the data are taken from short time tensile tests where these are available.

(ii) Young's Modulus at temperature.

(iii) Short time creep data at temperature. These are taken from U.S. Air Force Project Rand. (Reference 1).

(iv) Recovery properties at room temperature of unstable alloys.

A useful collection of papers on the behaviour of metals at elevated temperatures is presented in Reference (2).

In illustration of an extreme case of the problem, Figures 1A and 1B (taken from Reference (3)) give the material loss from spheres of various materials due to ablation or scaling off of the surface material from contact with or envelopment by the fireball. Data for three types of 10-inch diameter spheres are shown; namely, solid steel, solid aluminium, and solid aluminium with small cylindrical wells filled with ceramic inserts. The one curve in Figure 1A represents all three types.

References:

(1) Project Rand. Report R-147, U.S. Air Force, June, 1949.
Ministry of Supply Gas Turbine Collaboration Committee
R.C.301, 16831. (Restricted Discreet).

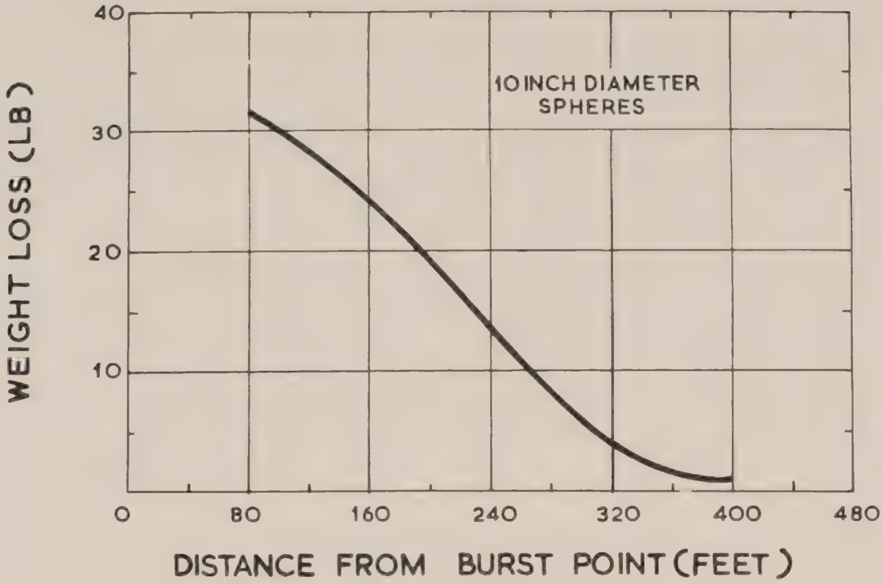
(2) Behaviour of Metals at Elevated Temperatures
- Institute of Metallurgists. (Iliffe & Sons, 1957)

(3) Capabilities of Atomic Weapons (1957)
U.S. Dept. of the Army, TM 23-200 (Confidential)

(4) High Temperature Effects in Aircraft Structures. N. J. Hoff
(Pergamon Press Ltd. 1958)

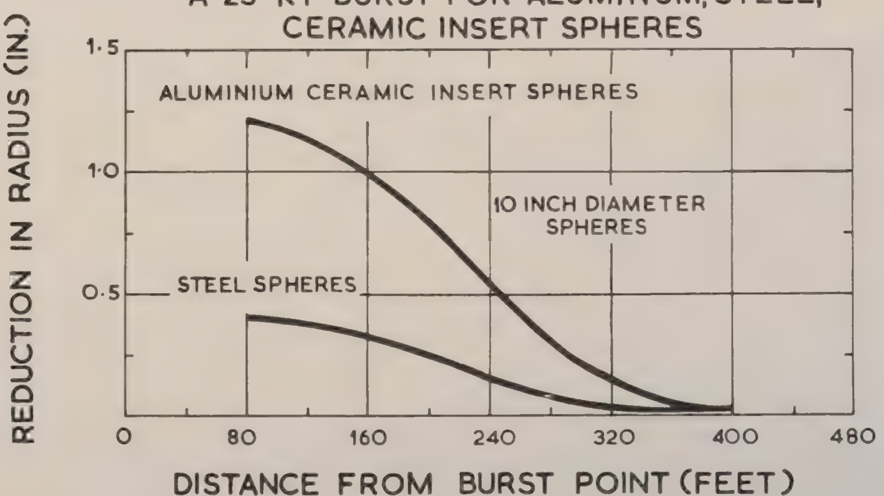
A.

WEIGHT LOSS WITH DISTANCE FROM A 23 KT BURST FOR ALUMINUM, STEEL, CERAMIC INSERT SPHERES



B.

REDUCTION OF SPHERE RADIUS WITH DISTANCE FROM A 23 KT BURST FOR ALUMINUM, STEEL, CERAMIC INSERT SPHERES



ABLATION OF METAL SPHERES BY THERMAL RADIATION

4.4.2. Mild Steel

Tensile strength at temperature - The variation of ultimate tensile strength with temperature of a range of plain carbon steels is shown in Figure 1 (Reference (1)). Up to 150°C the drop in strength is negligible. The strength increases up to about 300°C, and then falls rapidly, passing the room temperature value at about 400°C. In contrast to the ultimate tensile strength, the 0.1% proof stress remains unchanged up to 200°C and then falls appreciably, as indicated by Figure 2, taken from Reference (2).

The changes in strength with temperature are substantially independent of period at temperature up to 400°C.

Young's Modulus at temperature - The fall in E with rising temperature is shown in Figure 3 (Reference (2)).

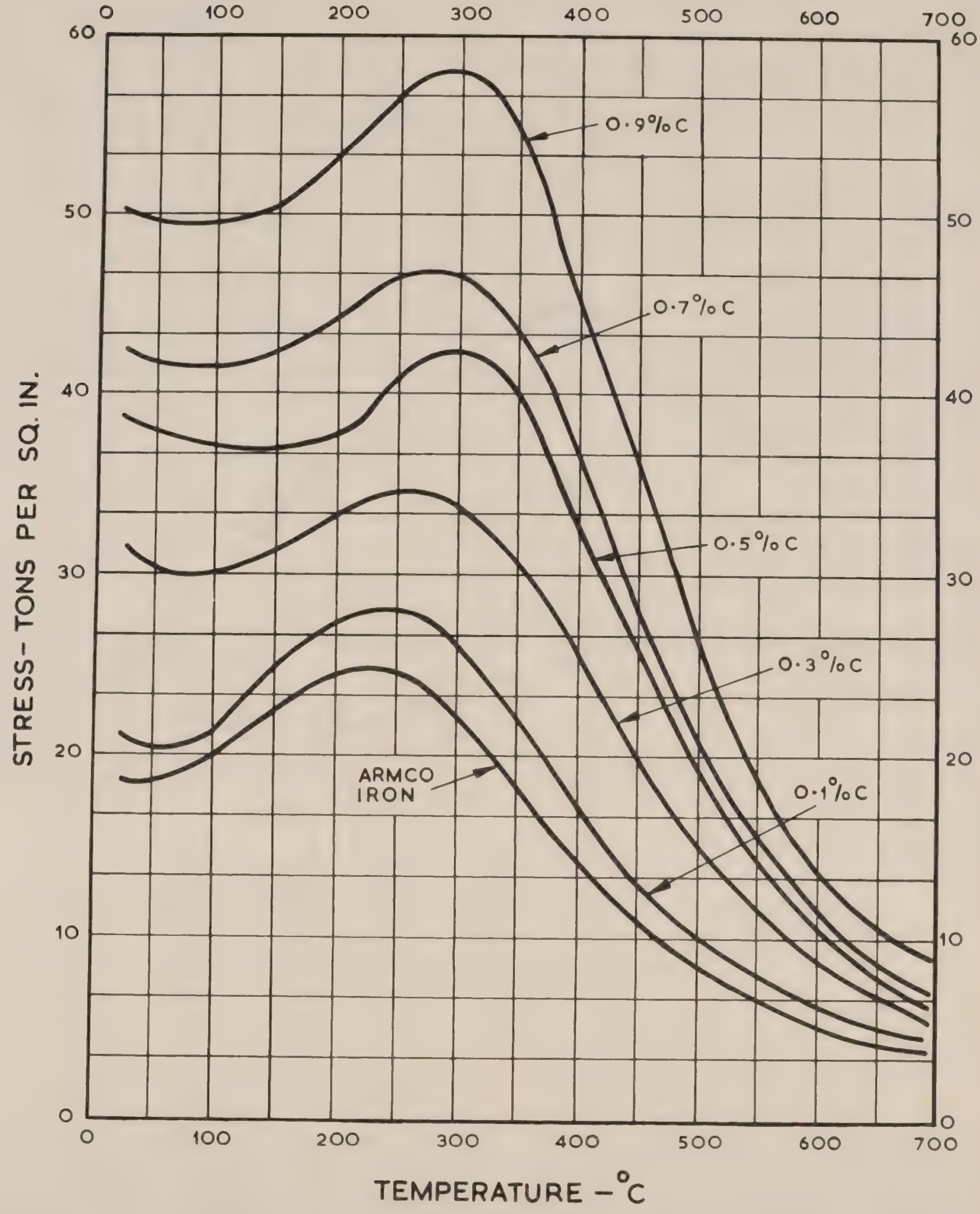
Short time creep properties - No data known.

Recovery strength - The room temperature strength is unaffected by heating, even for prolonged periods, at up to 400°C.

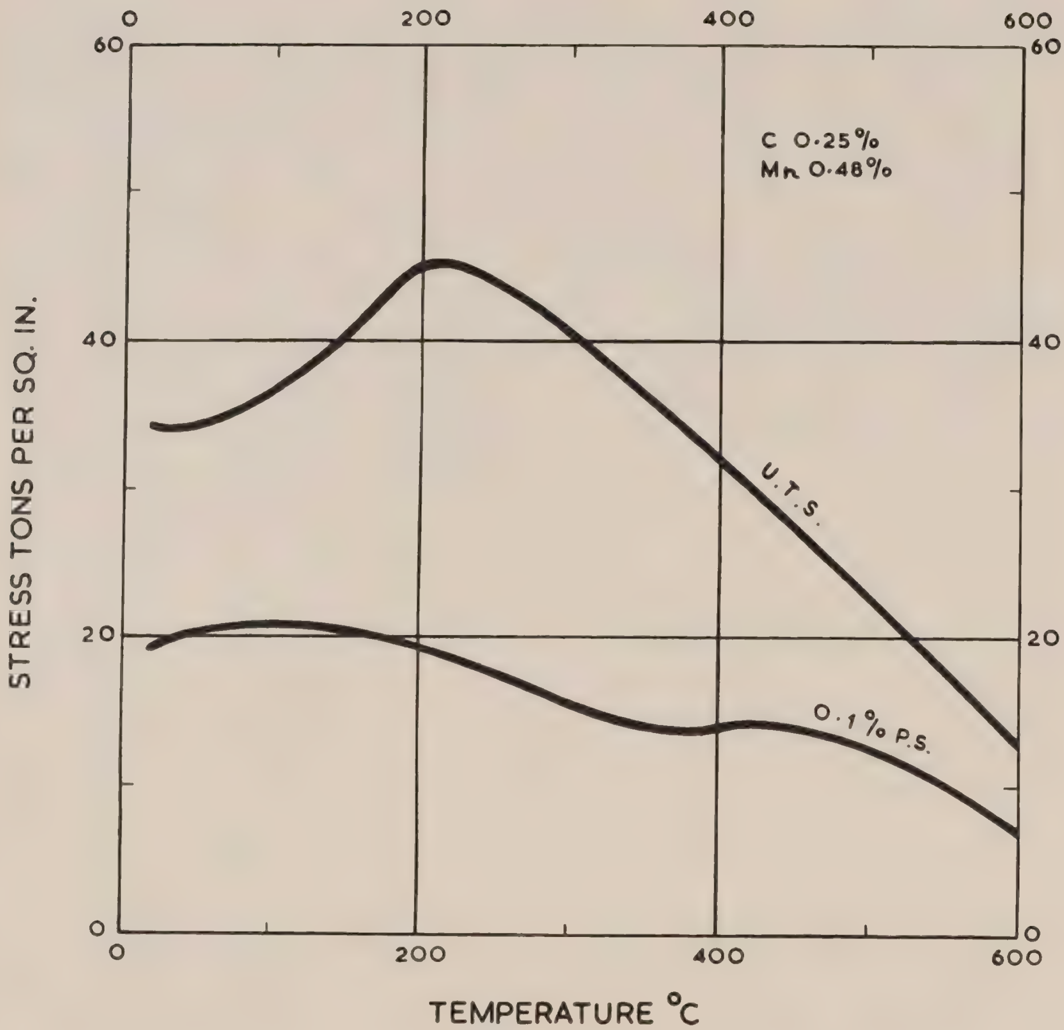
References

(1) Metals, Vol. 1. Carpenter and Robinson, page 177.

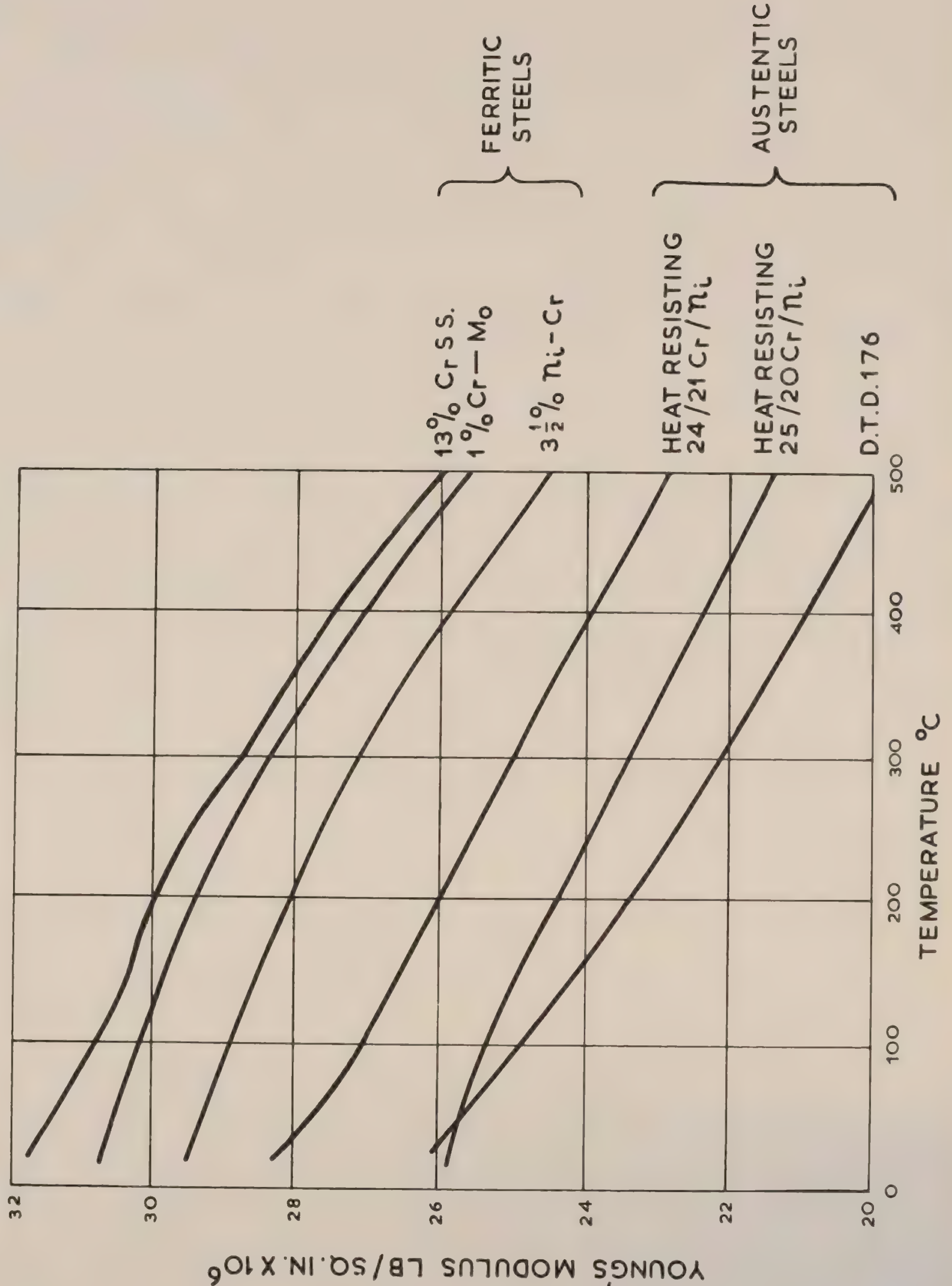
(2) R.A.E. Technical Note Met. 199, June, 1954. "The Effect of Heating Steels to Moderately Elevated Temperatures".



VARIATION OF ULTIMATE TENSILE STRENGTH WITH TEMPERATURE FOR A RANGE OF CARBON STEELS



VARIATION OF STRENGTH OF MILD STEEL
WITH TEMPERATURE



VARIATION OF YOUNG'S MODULUS WITH TEMPERATURE

4.4.3. Carbon and Low Alloy Steels

Tensile strength at temperature - The percentage fall in proof stress and ultimate tensile strength of a range of structural steels with rise of temperature is shown in Table 1. The results may be summarised as follows:-

	150°C	250°C	350°C
Proof stress	Drop of 10%	Drop of 15 to 20%	Drop of 20 to 25%
Ultimate tensile strength	Drop of 4 to 8%	Drop of 0 to 5%	Drop of 10 to 15%

EN110 nickel chrome molybdenum steel, however, retains its properties almost unchanged up to 300°C.

Young's modulus at temperature - Typical data for ferritic steels are shown in Figure 3, Section 4.4.2. Detailed figures for many steels are given in Reference (1).

Short time creep properties - The only data available are for SAE.4130 chrome molybdenum steel sheet at 650°C. These are summarised in Table 2.

Recovery strength - Periods of a few minutes at temperatures up to 400°C are not expected to have any permanent effect on tensile properties or to produce temper brittleness, except perhaps in the case of ultra high tensile steels tempered at 200 to 250°C. No data are available on the effect of short period heating on these steels, but it is thought that some loss of strength might occur at 300°C and more.

References

(1) R.A.E. Technical Note Met. 199, June, 1954. "The Effect of Heating Steels to Moderately Elevated Temperatures."

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TABLE 1

Tensile properties of carbon and low alloy structural steels at elevated temperatures

(The properties are substantially independent of period at temperature)

	Steel	Form	Heat Treatment	Room temp. properties tons/sq.in.		Percentage drop in properties at temperature													
						100°C		150°C		200°C		250°C		300°C		350°C		400°C	
				FS	UTS	FS	UTS	FS	UTS	FS	UTS	FS	UTS	FS	UTS	FS	UTS	FS	UTS
1.	Carbon manganese, weldalile, C 0.23%, Mn 1.7%	Bar		26 (0.2%)	39	4 (0.2)	+2	9 (0.2)	+5	14 (0.2)	+8	18 (0.2)	+12	21 (0.2)	+10	22 (0.2)	+2	22 (0.2)	10
2.	Manganese molybdenum, C0.43% Mn 1.8%, Mo 0.21%	Bar	WQ 815°C T 540°C	55 (YP)	61	7 (YP)	4	9 (YP)	5	11 (YP)	4	14 (YP)	4	18 (YP)	4	24 (YP)	8	32 (YP)	14
3.	1% chrome molybdenum, C0.38% Cr 1.0%, Mo 0.20%	Bar	OQ 845°C T 625°C	57 (YP)	64	9 (YP)	3	10 (YP)	4	11 (YP)	4	10 (YP)	5	14 (YP)	5	19 (YP)	9	26 (YP)	16
4.	1% chrome molybdenum EN 20	Bar	As En 20	61	66	-	-	-	-	19	2	21	+1	24	1	29	8	32	15
5.	Nickel chrome molybdenum S.11 (EN.23)	Bar	As En 23	50	60	8	7	10	8	14	9	14	5	16	1	22	10		
6.	Nickel chrome molybdenum EN.24	Bar	As En 24	65	72	8	5	11	7	16	8	14	6	20	9	24	13		
7.	Nickel chrome molybdenum EN.25	Bar	As En 25	70	77	7	5	11	7	18	8	18	6	20	9	24	13		
8.	Nickel chrome molybdenum EN.110	Bar	As En 26	56	72	+3	4	1	5	3	7	1	5	6	8	15	15		
9.	Chrome molybdenum SAE.4130	Sheet	OQ 900°C T 370°C	62	64					40	23							48	28 (at 427°C)

Data for steels 1 to 8 from ref. 3, for steel 9 from ref.1
YP - Yield point, i.e. limit of proportionality.
FS - 0.1% proof stress unless otherwise stated
UTS - Ultimate tensile strength.

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TABLE 2

Short time creep of steels

Metal	Condition	Room temp. strength tons/sq.in.		Heating rate °C per sec.	Temp. of test °C	Thermal expansion %	Stress, tons/sq.in to give 2% total extension			Stress to give 4% total extension		
		0.2% P.S.	U.T.S.				6 secs.	12 secs.	30 secs.	6 secs.	12 secs.	30 secs.
Steel Chromium molybdenum SAE 4130 0.30C 0.9Cr 0.2Mo	Annealed 1 hr. at 900°C			52-66	650	1.12	13.8	12.5	10.0	14.0	13.5	12.7
Chromium molybdenum SAE 4130 0.30C 0.9Cr 0.2Mo	OQ from 900°C T 1 hr. 370°C	63.5	64.5	52-66	650	1.12	>14	12.7				>15

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4.4.4. Heat Resisting Steels

These are of two types, the austenitic (high chromium and high nickel) and the ferritic (high chromium with low nickel, and high chromium with high nickel plus other elements which destroy the austenite stability imparted by nickel).

Tensile strength at temperature - Some typical data are given in Table 1. These steels retain their properties well, and are being actively developed for high speed aircraft structures.

Young's modulus at temperature - Typical data are shown in Figure 3, Section 4.4.2. A steady drop in E occurs, but the values for ferritic steels are appreciably higher at any temperature than those of austenitic steels.

Short time creep data - Data for two types of 18/8 steel are given in Table 2. Reference (1), from which the data where taken, includes similar information for a number of high temperature alloys, viz. 25 Cr - 20 Ni - 2 Si steel, inconels, hastelloys and stellite.

Recovery properties after heating - Recovery is normally complete for short periods of heating up to 500°C.

References

(1) Project Rand, Report R-147, U.S. Air Force, June, 1949.
Ministry of Supply Gas Turbine Collaboration Committee RC.301. 16831. (Restricted/Discreet)

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TABLE 1

Tensile properties of heat resistant structural steels at elevated temperatures

(The properties are substantially independent of period at temperature).

Steel	Form	Heat Treatment	Room temp. properties tons/sq.in.		Percentage drop in properties at temperature													
					100°C		150°C		200°C		250°C		300°C		350°C		400°C	
			PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS
1. Stainless iron, C 0.1% max.,CR 13.5	Bar	-	23	29	9	10	13	15	13	18	13	18	9	18	13	20	17	23
2. Stainless steel B.S. S62 C 0.25%,Cr.13.5	Bar	-	30	45	10	6	13	11	13	13	17	15	17	18	20	20	23	22
3. Stainless steel DTD.166 Austenitic	Sheet	Cold rolled	50	57	18	10	22	12	24	14	26	16	26	16	28	16	28	17
4. Stainless steel DTD.176 Austenitic	Bar	Annealed	12	42	25	19	25	24	25	26	25	29	25	29	25	29	25	29
5. Stainless steel Rex 448 Cr 11% with Mo, V, Nb	Sheet	-	58	77	3	8	9	10	17	12	17	12	17	13	22	18		
ditto	Bar	Heat treated	55	70	5	6	9	9	13	11	13	13	13	17	15	20	16	26

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TABLE 2

Short time creep of steels

Metal	Condition	Room temp. strength tons/sq.in.		Heating rate °C per sec.	Temp. of test °C	Thermal expansion %	Stress, tons/sq.in. to give 2% total extension			Stress to give 4% total extension		
		0.2% P.S.	U.T.S.				6 secs.	12 secs.	30 secs.	6 secs.	12 secs.	30 secs.
Stainless steel, 18/8, 0.02C	Annealed 1100°C	14.0	36.0	52	815	1.63	9.0	4.9	3.6	9.8	8.0	6.7
Stainless steel Type 347, 18/8 + Cb.	Half hard	65.6	67.5	52	650	1.28		31.6	19.2	35.7	34.8	33.5

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4.4.5. Aluminium Alloys

The stronger aluminium alloys rely for their strength on a solution heat treatment followed by an incipient precipitation induced by ageing at temperatures ranging from room temperature to 200°C depending on the alloy. Strength falls with rise of temperature, and when the ageing temperature has been passed, the fall in strength due to discrete precipitation is rapid and, in part, permanent. These gross and permanent changes occur rapidly at temperatures from 200°C and are within the range which might be reached by unprotected structures subject to heat flash. The temperatures are thus much lower than those at which somewhat analogous metallurgical changes occur in steels. Some aluminium alloys become susceptible to corrosion or stress corrosion at temperatures much lower than 200°C, but no data are available on whether this type of change occurs during very short periods of heating.

Tensile strength at temperature - Much information is available on the properties of cast, forged and extruded alloys at temperatures up to the levels at which reversible changes occur (References (1), (2) and (3)). Few data exist however, for the critical temperatures, and few short time tensile tests have been made. Table 1 lists the properties of some typical types of alloy.

Young's modulus at temperature - The Young's Modulus drops steadily with temperature. It is substantially independent of reversible or irreversible changes in other tensile properties.

Short time creep data - Available data are confined to 2S commercially pure aluminium sheet, and 75S alloy sheet, equivalent to DTD.687. These are summarised in Table 2.

Recovery properties after heating - The room temperature tensile properties of two alloys have been determined after short periods of heating (Reference (1)). Results are summarised in Table 3.

No data have been found for other alloys. Table 4 indicates the dangerous temperatures for a range of alloys; for L71 and L73 and for DTD.687, the figures are taken from Table 3, and for the remaining alloys estimates have been made by analogy.

Some recent combined transient heating and static loading tests on a Valiant aileron are reported in Reference (4).

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TABLE 1

Strength of representative aluminium alloys at elevated temperatures.

Alloy	Strength at room temp. tons/sq.in.		Percentage drop in properties at temperature											
			150°C 1 hr.		150°C 10 hrs.		200°C 1 hr.		200°C 10 hrs.		250°C 1 hr.		250°C 10 hrs.	
	0.1% PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS
DTD.364 bar (Al Cu type aged 200°C	27.5	33.0	7	15	7	12	18	30	24	30	47	51	64	67
DTD.683 bar (Al Zn Mg type, aged 130°C)	28.0	34.0	16	24	16	27	41	32	50	57	68	71	77	78
75 ST sheet (Al Zn Mg type)	31.6	36.4					63*	56*						
L.42 (RR59) bar (aged at 200°C)	19.5	29.5	5	14	5	14	10	22	5	24	20	37	28	44

*"Short time test" at 205°C.

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TABLE 2

Short time creep data on aluminium alloys

Metal	Room temp. strength tons/sq. in.		Temp. of test	Thermal expansion %	Stress, tons/sq. in. to give 2% total extension			Stress to give 3% total extension			Stress to give 4% total extension		
	0.1% P.S.	U.T.S.			6 secs.	12 secs.	30 secs.	6 secs.	12 secs.	30 secs.	6 secs.	12 secs.	30 secs
Aluminium sheet 2S commercially pure	8.0	8.3	149°C	0.32	7.4	7.2	6.7	7.5	7.3	6.9	-	-	-
			205°C	0.44	-	6.2	4.9	-	6.3	5.3	-	-	5.4
			315°C	0.83	-	2.5	1.6	-	2.6	2.1	-	-	2.4
Aluminium alloy sheet 75 ST, heat treated and aged, equivalent to DTD.687	31.7	36.5	149°C	0.30	29.5	28.4	27.3	30.0	28.8	27.6	-	29.0	28.0
			205°C	0.43	-	22.0	21.2	-	22.0	21.6	-	22.0	21.6
			315°C	0.83	-	5.8	5.6	-	5.8	5.6	-	5.8	5.6

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TABLE 3

Recovery Properties of Aluminium Alloys After Heating.

Alloy	Room temp. properties tons/sq.in.		Period at temperature secs.	Percentage drop in room temp. properties after heating									
				180°C		200°C		250°C		300°C		340°C	
	PS	UTS		PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS
Aluminium alloy sheet DTD.546	25.0	30.0	5	0	0	0	0	3	2	18	11	33	17
			10	0	0	0	0	4	2	22	13	40	21
			30	0	0	0	0	6	4	28	18	49	28
Aluminium alloy sheet DTD.687	30.0	34.0	5	0	0	0	0	18	15	28	17		
			10			3	5	20	16	38	23		
			30			12	10	25	20	48	30		

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TABLE 4

Alloy	Ageing Temperature	Damage Temperature
NS5, 3.5% Mg type	-	350° by annealing
NS6, 5% Mg type	-	Ditto, but may become susceptible to stress corrosion
H10, Mg Si type	180°C	250°C
H14, Cu type	Room temperature	250°C but may become more susceptible to corrosion
H15, L70, L72 Cu Si Fe type	Room temperature	250°C. At lower temperatures the material will age to L71, L73
H15, L71, L73 Cu Si Fe type	Up to 205°C	250°C
DTD.687 Zn Mg Cu type	130°C	200°C

References

(1) R.A.E. Technical Note Met. 197, May, 1954. The tensile Properties of D.T.D.546 & D.T.D. 687 after heating at elevated temperatures."

(2) Bristol Aeroplane Company. "Properties of Wrought and Cast Aluminium and Magnesium Alloys at Atmospheric and Elevated Temperatures", by P.H. Frith. To be issued in parts in the S & T. Memo. Series.

(3) Handley Page, Ltd., Stress Note 52, May, 1955. To be issued in the S.& T. Memo. Series.

(4) R.A.E. Test Note Structures 1519. July 1958. Combined Transient Heating and Static Loading Test of a Valiant Aileron. (Confidential)

4.4.6. Magnesium Alloys

The structural magnesium alloys are of two types, the magnesium aluminium type and the magnesium zinc zirconium type. The former type is not strengthened by solution heat treatment if the aluminium content is below about 9%, as is the case for wrought alloys; thus, although heating may induce precipitation, there is little permanent effect on properties until a temperature of about 200°C is reached, at which grain growth and permanent weakening begin. The magnesium zinc zirconium alloys are not susceptible to a solution heat treatment; grain growth occurs at above 250°C, but is relatively slow.

Tensile strength at temperature - Some figures for the strength of typical wrought magnesium alloys at elevated temperatures are given in Table 1.

The figures show that the fall in properties is very marked. Falls of this order are not found in the cast alloys containing zirconium and rare earths; attempts are being made to develop wrought alloys of this type.

Short time creep data - Some data on two alloys are summarised in Table 2. Data for ZW1 extruded bar, in which the stresses required to produce strains of from 0.05% to 0.5% at 150°C, 180°C and 200°C, have also been published (Reference (1)).

Recovery properties after heating - No permanent effect on room temperature properties is likely to result from heating to temperatures of up to 200°C. Above this temperature, permanent softening will occur.

The only data found are some R.A.E. results (Reference (2)), on the effect of 10 second periods of heating on ZW3 (DTD.626) sheet. At 250°C, no effect was found, and at 320°C a drop of 4% in the 0.1% proof stress occurred.

References

(1) Magnesium Elektron, Ltd., Technical Bulletin No.1, July, 1953.

(2) R.A.E. Technical Memorandum Met. 600, October, 1955.

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TABLE I

Strength of Representative Magnesium Alloys at Elevated Temperatures

Alloy	Room temp. props. tons/sq.in.		Percentage drop in Properties at Temperature									
			50°C		100°C		150°C		200°C		250°C	
	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS	PS	UTS
AZ31 "Wrought" (PS values are 0.2%)	12.8	17.0	12	4	30	19	49	38	67	55	78	69
AZ31, FS1A, sheet	10.2	17.2							73 at 205°C	69 at 205°C		
AZM bar, D.T.D.259		18.8		8		19		31		51		73
ZW3 sheet, D.T.D.626		18		11		33		51		67		78
ZW3 bar, D.T.D.622A	16.4	21.0	19	20	41	43	62	53	83	60	95	68
ME-10, sheet (Mn Ce alloy sq. to AM537) Ann.	10.2	15.0							46 at 205°C	51 at 205°C		
ME-10, h.t. 1 hr. 482°C aged 16 hr. 205°C	7.3	12.5										

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TABLE 2

Short time creep of magnesium alloys

Metal	Room temp. strength tons/sq. in.		Temp. of test	Thermal expansion %	Stress, tons sq. in. to give 2% total extension			Stress to give 3% total extension			Stress to give 4% total extension		
	0.1% P.S.	U.T.S.			6 secs.	12 secs.	30 secs.	6 secs.	12 secs.	30 secs.	6 secs.	12 secs.	30 secs.
Magnesium alloy sheet FS1A, equivalent to AZ31	11.0	17.2	149°C 205°C 315°C	0.38 0.53 0.92	9.8 5.8 2.7	9.8 5.5 2.0	6.3 5.0 1.0	9.8 - -	9.8 5.7 2.2	7.4 5.3 1.7	- - -	9.8 - -	7.8 5.4 2.1
Magnesium alloy sheet ME10, (Mn Ce alloy) Annealed	10.2	15.0	149°C 205°C	0.31 0.43	9.2 7.3	8.8 7.2	8.3 6.7	9.3 7.3	8.9 7.2	8.6 7.0	9.4 7.3	9.1 7.3	8.7 7.1
Ditto, heat treated as Table 1	7.3	12.5	315°C	0.78	-	3.6	3.1	-	-	3.4	-	-	3.6

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4.5. Thermal Damage to Miscellaneous Service Equipment

4.5.1. Chemical Warfare Equipment

(a) Service respirators - The exposure of obsolescent respirators G.S. during Operation Totem (Reference (1)), showed that there was no increased hazard due to ignition of the rubber mask following a nuclear explosion, but that on the contrary, the mask gave a considerable measure of protection against facial burns. (See Section 4.2.1 for details.)

A further exposure trial during Operation Buffalo (Reference (2)) was intended to provide information on the new Service respirator (which is now in the final stages of Service trials and development), particularly with regard to the pneumatic periphery. It was also desired to obtain information on respirators within haversacks. Twelve respirators (Type D46/36) which were exposed on dummy heads to thermal doses from 2-96 cals/cm^2 behaved similarly to the respirators exposed at Operation Totem. They remained undamaged up to 8 cals/cm^2, and the majority would probably have been serviceable up to 12 cals/cm^2, in spite of surface melting of the external surface of the rubber. The internal surfaces, including the air bag, were not affected even at 32 cals/cm^2, and it is clear that external heat damage to the mask and head harness is the controlling factor from the respirator serviceability aspect. The new respirator is therefore no more vulnerable than the old respirator G.S., and owing to the pneumatic fitting would certainly give greater protection against heat, but this advantage would be offset by the increased exposure of the eye region through larger eyepieces.

Respirators in haversacks were unaffected up to 32 cals/cm^2, and at higher levels impact with surrounding objects as a result of blast is likely to be the factor controlling serviceability. The haversacks themselves showed slight discolouration at 6 cals/cm^2, but remained intact, although severely scorched at 32 cals/cm^2. At higher levels they were torn apart by blast, but were still not seriously affected by the heat.

It appears reasonable to conclude that worn respirators will remain serviceable under conditions in which the incidence of lethality for exposed men is high. (Cf. Chapter 7)

(b) Kits, Vapour Detector - Of the six K.V.Ds exposed at Operation Buffalo, four were almost completely destroyed by burning, and were not returned to the U.K. for examination. Of the two returned, no particulars of the thermal dose received were known in one case, and the other kit was at a site which received 48 cals/cm^2. Of the two kits examined, the canvas carrying cases were badly scorched, the cotton seam had given way, and the strengthening plastic sheet had come out. Tests were carried out in the normal way for mustard gas and nerve gas vapour, with results normal for the K.V.D., showing in particular that the tablets had not been adversely affected by the heat.

(c) Detector Powder - Six tins of detector powder were exposed to various thermal doses with the following results:-

8-12 cals/cm^2 - slightly scorched
16-24 cals/cm^2 - scorched and dented
32-48 cals/cm^2 - blackened and badly dented at one side.

In all cases the powder had not been affected in any way and responded to tests for liquid contamination.

(d) Detector Paper - Boxes of detector paper pads were exposed at sites receiving heat doses of 8, 12, 16, 24 and 32 cals/cm^2. Though scorching and blackening had occurred on one side of the boxes, this was entirely superficial and had not affected the paper in any way. Response to liquid contamination was normal.

Some single sheets of paper were also exposed to thermal doses ranging from 2-128 cals/cm^2. Below 6 cals/cm^2 there was no visible effect; above this dose scorching and charring occurred progressively, until, at the highest doses the middle of the sheet was burnt out. In all cases reactions were obtained in tests for liquid contamination, though in some cases where the paper had been scorched badly, very fine contaminating drops might not be seen, particularly the yellow colour of the nerve gas test.

References

(1) A.W.R.E. Report No. T77/54, Operation Totem. "Effects on Respirators Anti-Gas (Confidential)

(2) A.W.R.E. Report No. T28/58. Operation Buffalo, Target Response Tests. Materials Group.
Part 9(a): Effects on Chemical Warfare Equipment (Confidential)

4.5.2. Aircraft Windscreens (Reference (1))

Three types of panels representing current practice in the construction of bullet-proof windscreens were exposed at a number of sites at Operation Buffalo to a 15-20 KT nuclear explosion. The types of panel chosen were:-

(a) bullet-proof panels 12" x 12" x 1.5", incorporating an annealed glass;

(b) front panels from a Vampire windscreen, length approximately 22 ins, width tapering from 12 ins. to 8 ins, thickness 2.2 ins.

(c) Hunter windscreen, length approximately 24 ins, width tapering from 13 ins. to 4 ins, thickness 1.5 ins.

The panels were exposed vertically in the metal frames, slightly above ground level, at sites which received thermal doses of 12, 16, 24, 32, 48 and 64 cals/cm^2 respectively.

Panels at the two nearest sites to ground zero were torn from their frames and thrown several yards, sustaining some impact damage. Frames at the remaining sites were buckled, but the panels were still in place. The exposure face was in all cases pitted by sand blasting, the degree of damage becoming progressively less with increased distance from ground zero. The light transmission had of course, been affected by this pitting, but it is doubtful if pitting would have occurred had the panels been exposed at the height and angle equivalent to their normal position in an aircraft. In no case had the Vinal interlayer been visibly affected by the thermal radiation. Detailed results are given in Table I.

TABLE I - Damage to Aircraft Windscreens at Operation Buffalo

Feet From GZ	Total Heat Dose $cals/cm^2$	Annealed Panel	Vampire Windscreen	Hunter Windscreen
1840	64	All glass layers cracked 1st layer 6 in. crack 2nd layer 3 in. crack 3rd layer 7 in. crack 4th layer 4 cracks max. length 6 in. Both exposed glass surfaces pitted	Broken in two. Rear face missing. All remaining glass layers heavily cracked. Some separation of inter-layer along cracks. Front face heavily pitted	Front and rear glass layers cracked. Front layer 5 cracks across width. Back layer three 1 in. cracks Front Face very heavily pitted
2070	48	Back two layers cracked. Rear 0.2 in layer three cracks maximum length 4 in. Rear 0.5 in. layer 4 in. crack. Front face pitted.	Rear face missing. Otherwise no cracks. Front face heavily pitted.	Front layer cracked, (7 in. length). Front face pitted.
2560	32	Back layer cracked (2 in. length). Front face pitted.	Rear face heavily cracked. Front face heavily pitted.	No cracks. Front face pitted.
2950	24	No cracks. Front face slightly pitted.	No cracks. Front face slightly pitted.	No cracks. Front face very slightly pitted.
3570	16	No cracks Front face slightly pitted	No cracks Front face slightly pitted	Back layer cracked (two 2 in. cracks) Front face very slightly pitted.
4050	12	No cracks Front face very slightly pitted.	No cracks. Front face very slightly pitted.	Front and back layers cracked at edge. Front layer 5 in. crack Back layer 1 in. crack No pitting.

It is concluded in Reference (1) that all three types of panel behaved very well. The impact damage (i.e. cracking and pitting) would probably not have occurred had the panels been exposed as part of aircraft, and in any case were at damage levels at which the aircraft themselves would have been rendered non-operational. The Vinal interlayer, although soon damaged by sustained exposure to comparatively low temperatures, was not affected even by the highest thermal flux to which it was subjected.

References

(1) A.W.R.E. Report No. T.28/58. Operation Buffalo Target Response Tests, Materials Group.
Part 9(c): Effects on Aircraft Windscreens.
(Confidential)

CHAPTER 5 - THERMAL DAMAGE TO VEGETATION

5.1. Types and Conditions of Vegetation

Under certain conditions, the employment of an air burst weapon over a forest or wild-land area, may cause fires. During the fire season*, even when the burning potential is low, fires may spread. Wild-land fuels are generally a mixture of thin and heavy fuel components. Thin fuels are typified by surface litter and grassland; heavy fuels by fallen branches. The thinnest fuel present determines the ignition energy for the mixture. Heavy fuels do not ignite and continue to burn by themselves, but thin fuels may serve as the source of a pilot flame and may spread fire after the end of the radiant pulse. The following information on types and conditions of vegetation has been obtained from Reference (1).

During the fire season, ignitions may be expected in kindling fuels where the total thermal energies exceed 2 - 3 cals/sq.cm. for a 1 KT weapon. As the yield increases, the minimum ignition energies increase as $W^{1/8}$, i.e. 8-10 cals/sq.cm. would be required from a 30 MT weapon to ignite the thinnest wild-land fuels.

It is estimated that very few ignitions will occur within a forest in which the tree canopy shades more than 20% of the ground surface. Green leaves on tree crowns smoke and char, but do not normally sustain ignition.

Table 1 summarises the conditions which exist in forest and heath areas etc., during the fire season; the latter varies in different locations according to temperature and rainfall.

* For definition see Table 1.

TABLE I

The Condition of Wild land Fuels During Fire Season

Fuel Type	Description	Amount and Density of fuel to constitute a fire hazard	Condition During Fire Season
Grass or heath	Grassland, dry bracken, ferns, seasonal plants	Uniform grass cover ½ ton or more per acre	Vegetation nearly dry or dead
Evergreen bush	Perennial evergreen shrubs and brush	75% or more area covered	15-25% by weight of leaves and twigs dead
Deciduous forest	Forest predominantly of broad-leaf trees, leaves of which die and fall each year	Ground covered with more or less continuous layer of dead leaves	Leaves off trees. Ground vegetation dead or non-existent
Coniferous forest	Forests of evengreen pines - needle bearing trees	Ground covered with a more or less continuous layer of dead needles and twigs	Needles and twigs dry enough to break easily when bent. Grass and other vegetation present dry or dead.

The majority of thin wild-land fuels which serve as kindling material are divided, in Table 2, into four classes corresponding to different minimum ignition energy levels. Ignition energies increase as fuel moisture content increases. Since ignition generally occurs on those surfaces most exposed to the atmosphere, ignition energies are a function of relative humidity, as shown in Figure 1.

TABLE 2

Classes of Thin Wildland Kindling Fuels (in order of flammability)

Class	Description
I.	Broadleaf and coniferous litter; mixture of fine grass, broken leaves and thin translucent broadleaf leaves.
II.	Hardwood and soft wood in various stages of fungoid decay.
III.	Dried or dead grass.
IV.	Conifer needles and thick, nearly opaque broadleaf leaves.

Fires may be blown out by blast depending on the time interval between ignition and arrival of the shock. Blowout is not expected in regions below 5 p.s.i. for fully exposed fuels. If the fuel is in a hole or pocket, the chance of blowout is materially decreased. When fires are not blown out, they generally increase in intensity owing to the action of the blast wind.

The principal factors, apart from the fuels present, that influence the burning potential of forest or wild-land areas, are the nature of the terrain, the wind speed close to the ground, the relative humidity, and the precipitation history. An approximate guide for evaluating the effects of weather or burning potential is given in Table 3. Fuels seldom burn vigorously, regardless of wind conditions when the fuel moisture is greater than 16 percent. This corresponds to an equilibrium moisture content for 80 percent relative humidity. About a quarter of an inch of rain renders fuels temporarily non-inflammable, and may extinguish going fires in thin fuels. The time required to restore the burning potential may vary from hours to days depending on local weather conditions. Surface fuels in the interior of forests are exposed to reduced wind velocities and generally have high fuel moistures due to shading by the canopy.

Table 3 - Burning Potential for Light Wildland Fuels During Fire Season (Terrains with slopes less than 20 percent)

Wind Speed 20 ft. above ground in the open	Relative Humidity (percent)			
	Below 15	15 - 40	40 - 65	65 - 80
Below 5 knots	Dangerous	Dangerous	Low	Low
5 - 10 knots	Critical	Dangerous	Dangerous	Low
10 - 15 knots	Critical	Critical	Dangerous	Low
Above 15 knots	Critical	Critical	Critical	Dangerous

Definitions (for Table 3)

Low - irregular fire perimeter, spread greatly affected by changes in fuel structure and topography, depth of fire small. Fire generally stops at roads and ridge-tops. Control action can be on an individual basis.

Dangerous - continuous intense fire front which moves rapidly. Frequently spots ahead. Aggressive organised action required to protect personnel and equipment.

Critical - conflagration-type fire, in heavy fuels readily crowns and spots as much as a mile ahead. Control action only when changes in fuel type or burning conditions permit.

Notes (a) For heavy fuels, use the classification for next higher wind speed.

(b) For terrain with slopes greater than 20 percent, use the classification for the next higher wind speed.

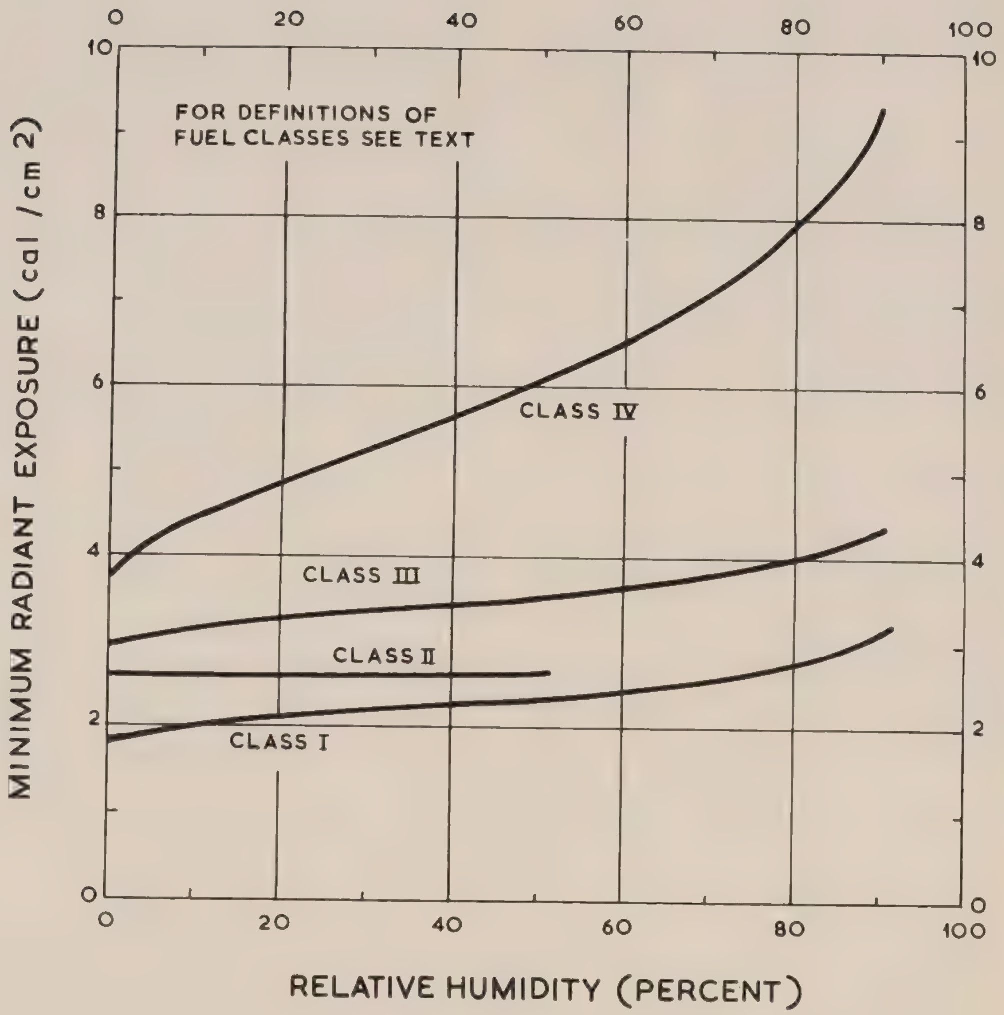
(c) For canopy shading 20 percent of the ground, reduce wind one class, and increase relative humidity one class.

(d) For full shading, reduce wind two classes and increase relative humidity two classes.

Details of damage to forests by airblast are given in Part III, Chapter 9, Section 9.9.

References.

(1) Capabilities of Atomic Weapons, (1957) U.S. Dept. of the Army TM 23-200. p.11-2. (Confidential)



MINIMUM RADIANT EXPOSURE FOR IGNITION OF WILDLAND KINDLING FUELS - SCALED TO 1 KT

5.2. The Results of Atomic Weapon Tests on Forest Fuels

During the U.S. Atomic Weapon Test "Operation Snapper", measurements were made of the minimum thermal energies required to ignite common forest fuels, (Reference (1)). Observations were also made to determine blast wave effects on the persistence of ignition and to provide field data against which laboratory source tests could be scaled.

Prepared fuel beds of conifer needles, hardwood leaves, grasses and rotton wood, were exposed in Operation Snapper to total thermal energies varying from 1 - 22 cals/sq.cm. Thickness and density of fuel particles were determined prior to the test. Fuel moisture at shot time was measured in duplicate field beds, similarly located, but outside the test area.

Post test fuel examinations showed that decayed materials and fine grasses ignited and continued to burn at distances from Ground Zero where the total thermal energy was approximately 3 cals/sq.cm. Following shots 3 and 4, decayed materials were still burning upon recovery at H + 2 hours. The following conclusions were made ffom the test results.

(i) Under fire-weather conditions (relative humidity less than 40%, air temperature greater than 35°F, fuel moisture less than 15%) in a forest area, atomic explosiions can be expected to ignite decayed and fine grassy fuels wherever the total thermal energy exceeds 3 cals/sq.cm.

(ii) Minimum ignition energies have been established to within approximately ± 10% for common wild-land fuels - pine needles, hardwood leaves, grasses and rotted materials.

(iii) Rotted or decayed materials and fine grasses which are ignited at low energy levels by atomic explosions, can spread fire to associated fuels which would not otherwise have been ignited.

(iv) Sparse tree crowns exposed to energies of 22 cals/sq.cm. effectively shade dead surface fuels so that few ignitions of these fuels can occur in their shadow. Dense green forest stands, with 100% crown closure, should offer few, if any, ignition points where persistent ignition and fire would occur.

References

(1) Operation Snapper, Project S .1. The Effect of Atomic Explosions on Forest Fuels. WT-506, AFSWP. (Confidential)

5.3. Estimated Effects of Atomic Weapons on Forests of N.W. Europe

An assessment has been made (Reference (1)) of the general effects of exploding atomic weapons over forests, with particular reference to blast and fire hazards. The degree of protection likely to be afforded by forests in N.W. Europe to stores, vehicles and personnel in them, has been examined, and also the possibility of exploding atomic weapons over forests in order to create obstacles to the movement of tracked and wheeled vehicles and personnel, has been assessed. Two areas in which obstacle belts might be created in forests were examined in detail; the area to the S.W. of Kassel, and the area between Uelzen, Gifhorn, and the Eastern Frontier.

The main conclusions reached in the Paper were:-

(i) The range for ignition of forest fuels by thermal radiation from atomic weapons will exceed the range of blast damage under fine weather conditions, but when the weather is not fine, blast damage becomes of major importance.

(ii) The probability of fires started by the ignition of forest fuels spreading and leading to a general conflagration is small at all seasons of the year in W. Europe, but limited danger periods may exist during spells of dry weather, especially in the spring and autumn.

(iii) Forests can provide useful protection against the thermal effects of atomic weapons, the amount of thermal shielding being proportional to the projected area of foliage between the weapon and the target. All the year round protection is available in the coniferous forests which make up 70% of the total in Germany, the deciduous forests can only provide thermal shielding when in leaf.

(iv) Forests provide little in the way of blast protection to man and material in them. Rather, falling trees and branches and other secondary blast effects may hurt or damage men and equipment at ranges where they would be unaffected in the open and may also prevent access to stores or equipments in woods attacked by atomic weapons until such time as a major clearance effort can be made. (See Part III, Chapter 9, Section 9.9 for details of blast damage to forests).

Reference

(1) The Effects of Atomic Weapons on Forests in N.W. Europe.
Operational Research Section, B.A.O.R. Report 3/56 (Confidential)

CHAPTER 6 - THERMAL DAMAGE TO BUILDINGS AND URBAN AREAS

6.1 Origin of Fires

There are two general ways in which fires can originate from a nuclear explosion. Firstly, by the ignition of paper, rubbish, window curtains, awnings, dry grass and leaves etc., as a direct result of the absorption of thermal radiation. And secondly, as an indirect effect of the destruction caused by the blast wave, fires can be started by upset stoves and furnaces, electrical short circuits and broken gas pipes. No matter how the fire originates, its subsequent spread will be determined by the amount and distribution of combustible materials in the vicinity. It will be seen therefore, that the development of fires accompanying a nuclear explosion depends on two factors; firstly, the number of points at which fire originates, and secondly, the character of the surrounding area.

A study of the mechanism of initiation and development of fires from a nominal (20KT) atomic bomb is made in Reference (1). It is concluded that primary fires were much more numerous than secondary fires after the atomic weapon bursts in Japan, and that a large number of primary fires would probably result from an atomic burst over a British city. The simple precaution of preventing the entry of heat flash through window openings would greatly reduce the risk of primary fires from an atomic bomb. The Hiroshima fire storm must therefore have been due to primary fires. Normal scaling of the figures given in Reference (1) suggests that the fire zone could extend beyond the blast damage zone in the case of megaton weapons burst over cities.

Reference (1) also examines the incidence of secondary fires from H.E. bombs in the United Kingdom and in Japan, and a detailed account of secondary fires from the fly bomb attack on London in 1944 is given. From this evidence it is deduced that one nominal atomic bomb on a British city would probably start about 300 large secondary fires requiring the attention of the Fire Service, and about 1,000 small debris fires which could easily be extinguished by fire guards, if they did not go out of their own accord. This is not a serious fire situation, and could hardly give rise to a fire storm comparable with that at Hiroshima (see Section 6.2.2 of this Chapter), since this would require about 10,000 large initial fires in the damage area.

The fact that accumulations of combustible rubbish close to a wooden structure represent a real fire hazard was demonstrated at the nuclear tests carried out in Nevada in 1953. In these tests, three miniature wooden houses each having a yard enclosed with a wooden fence, were exposed to 12 cals/sq.cm. of thermal radiation from a weapon of about 30KT. The first house had weathered siding showing considerable decay, but the yard was free from rubbish. The second house also had a clean yard, and further, the exterior siding was well maintained and painted. In the third house the siding, which was poorly maintained, was weathered, and the yard was littered with rubbish. Following the explosion, the third house soon burst into flame and was burnt to the ground. The first house did ignite but it did not burst into flame for 15 minutes. The well-maintained house with the clean yard suffered scorching only. It was also noted that the wood of a newly erected white-painted house exposed to about 25 cals/sq.cm. was badly charred but did not ignite, (Reference (2)).

The incidence of wooden houses is very small in the United Kingdom and so the possibility of ignition from the outside is not nearly so great as in

this American test. However the test also showed that the radiation entering through windows caused combustion inside the houses, and this was sustained in the case where much combustible material was lying about, but died out in a tidy room with a low combustible content.

Critical energy data for various combustible materials are given in Section 4.2, Chapter 4, and some further values, given in Table 1 below, are taken from p.307 of Reference (3).

Table 1

Thermal Energies for the Ignition of Household Materials

Material	Weight (oz/sq.yd.)	Ignition Energy (cal/sq.cm.)	
		20 kilotons	10 megatons
Dust mop (Oily, grey)	-	3	5
Newspaper, shredded	2	2	4
Paper, crepe (green)	1	4	8
Newspaper, single sheet	2	3	6
Newspapers piled flat, surface exposed	-	3	6
Newspapers, weathered, crumpled	1	3	6
Newspaper, crumpled	2	4	8
Cotton waste (oily, grey)	-	5	8
Paper, bond typing, new (white)	2	15	30
Paper, Kraft, single sheet (tan)	2	7	14
Matches, paper book, blue heads exposed	-	5	9
Cotton string scrubbing mop, used (grey)	-	6	10
Cellulose sponge, new (pink)	39	6	10
Cotton string mop, weathered (cream)	-	7	13
Paper bristol board, 3 ply (dark)	10	8	15
Paper bristol board, 3 ply (white)	10	12	25
Kraft paper carton, flat side, used (brown)	16	8	15
Kraft paper carton, corrugated edges exposed, used (brown)	-	12	25
Straw broom (yellow)	-	8	17
Excelsior, Ponderosa pine (light yellow)	2 lb/cu.ft.	5	12
Tampico fibre scrub brush, used (dirty yellow)	-	10	20
Palmetto fibre scrub brush, used (rust)	-	12	25
Twisted paper, auto seat cover, used (multicolor)	13	12	25
Leather, thin (brown)	6	*15	*30
Vinyl plastic auto seat cover	10	*16	*27
Woven straw, old (yellow)	13	*16	*33

*Indicates material was not ignited to sustained burning by the incident thermal energy indicated.

Since thin kindling materials quickly reach equilibrium with the moisture condition of the atmosphere, the relative humidity has a marked effect on the critical ignition energy of any such fuels. Under conditions of high humidity, the ignition energy may be increased by 30 to 50 per cent.

There is another point in connection with the initiation of fires by thermal radiation which needs consideration. This is the possibility that the flame resulting from the ignition of a combustible material may be subsequently extinguished by the blast wind. It was thought that there was evidence for such an effect from an observation made in Japan, but this may have been an exceptional case. The matter has been studied both in connection with the effects in Japan, and at various nuclear tests, and the general conclusion is that the blast wind has no significant effect in extinguishing fires. (Reference (3), p. 319).

References

(1) Home Office Report CD/SA 6 - "The Atomic Bomb as a Fire Raiser - a Study of the Mechanism of Initiation and Development".
(Secret).

(2) U.S. Civil Defence Administration Film,

"The House in the Middle".
(Home Office Film Library).

(3) The Effects of Nuclear Weapons, U.S.A.E.C., 1957.

6.2 Fire Spread

6.2.1 Local Fire Growth

Once ignition has occurred, a material continues to burn if sufficient heat is transferred to it from the flame. The amount of heat required depends upon the amount of moisture present in the material and the thickness and shape of the specimen. For example, thin splints of wood or thin films continue to burn after ignition, whereas boards one inch thick do not. Supplementary heat is required from external sources which, in the early stages of an ordinary fire, is often supplied by the igniting source. This supplementary heat does not normally exist in atomic explosions, and so a thick material isolated from other surfaces, goes out.

If flame persists and spreads over the surface of ignited materials, it is possible that other combustible materials in the vicinity may be ignited. The more objects that are ignited the greater the rate of supply of heat to both burning and unburnt materials. The materials already burning may burn more fiercely, and any remaining unburnt material in the room may very quickly be exposed to a rate of heat that may cause it to ignite. At this stage the fire spreads rapidly through the room. This is often referred to as the 'flashover'. If the walls or ceiling are made of combustible building boards, or the room has a high surface area of combustible material, this stage is reached more quickly.

Following the atomic explosions at Hiroshima and Nagasaki, once the fires had started there were several factors directly related to the destruction caused by the explosions that influenced the spread of fires. By breaking windows and blowing in or damaging fire shutters, by stripping wall and roof sheeting, and by collapsing walls and roofs, the blast made many buildings more vulnerable to fire. Non-combustible (fire-resistive) structures were often left in a condition favourable to the internal spread of fires by damage at stairways, lifts, and in fire-wall openings, as well as by the rupture and collapse of floors and partitions. On the other hand, when combustible frame-buildings were blown down they did not burn as rapidly as they would have done had they remained standing. Further, the non-combustible debris produced by the blast frequently covered and prevented the burning of combustible material. There is some doubt therefore, whether, on the whole, the effect of the blast damage was to facilitate or hinder the development of fires at Hiroshima and Nagasaki.

6.2.2. Mass Fires

In peace-time, the term 'conflagration' is often used loosely to describe fires burning in several adjacent buildings simultaneously. Even though fire spread may occur from these buildings to other adjoining ones, such fires are unlikely to spread to any great distance because of existing fire breaks and intensive fire-fighting. Mass fires of the type to be expected in the event of atomic attack, on the other hand, are great fires burning entirely out of control. These fires have the greatest potential as destroyers of life and property and are of such an extensive nature that consideration of fire risk to an individual building or small group of buildings becomes meaningless. Mass fires which have been observed in the past consist of two types, fire storms and conflagrations.

Fire storms are expected on the rapid ignition of large areas in the absence of a strong ground wind. In such a case the interacting fire winds started by the many individual fires merge the aggregate blazes into one inferno with its own pillar of burning gases rising almost vertically above the centre of the ignited area. The rapid rise of hot and burning gases causes an influx of new air at the base of the pillar. This on-rush of air, or fire wind, reaches gale-like proportions as it heads towards the fire centre, where sufficient fuel is available and no large fire breaks are found. Such fires raise to the ignition point all combustibles, and complete burnout within the affected area follows. Even where no burning occurs, the fire wind collapses buildings, uproots trees, and sends objects as large as motor-cars spiralling into the air. However, since all winds blow towards the centre of the fire, there is usually little fire spread to the areas beyond those originally affected. A description of a fire storm which developed in Hiroshima about 20 minutes after the detonation of the nuclear bomb, is given in Reference (1).

A conflagration, on the other hand, is a great fire which moves along the ground under the influence of strong winds. In this case the initial fires, in merging, spread considerably to leeward. The pillar, once it has been established, slants appreciably to leeward, and large numbers of firebrands are showered upon the leeward region. Also, the higher the wind velocity, the more the pillar leans and the closer the hot and burning gases approach combustible materials on the ground. The chief characteristic of the conflagration therefore, is the presence of a fire front, an extended wall of fire moving to leeward preceded by a mass of pre-heated turbid burning vapours and by a large number of spot fires initiated by the firebrands. The progress and distributive features of the conflagration consequently may be much greater than those of the fire storm, for the fire continues to spread in the downwind direction until it can reach no more combustible material.

Initiation and spread of these mass fires following enemy attack depend to a large extent on the fire susceptibility of an area. The fire susceptibility, in turn, is influenced not only by the presence of the kindling fuels already discussed, but also by the presence and spacing of all combustible materials in the area. Thus, the ignition point is of concern only if sufficient contiguous fuel is available to ensure the formation of a growing fire. For this initial fire to be of major importance it must burn long enough to permit spread to additional combustible material nearby. Consequently, fuel factors which affect fire susceptibility in conventional (industrial) fires are also of importance in consideration of thermal vulnerability to atomic explosions. Among these important factors are size and combustibility of structures, fuel value of

building contents, continuity of combustible construction, and the presence of fire breaks.

A British scheme for the zoning of towns for fire susceptibility is described in Reference (2). This scheme has now been applied to the major towns in the United Kingdom. Fire zone maps have three important uses:-

(i) They indicate where large area fires are possible, and where efforts to reduce fire risk should be concentrated.

(ii) They provide a standard basis for schemes for emergency water supplies, and for the development of wartime fire-fighting tactics.

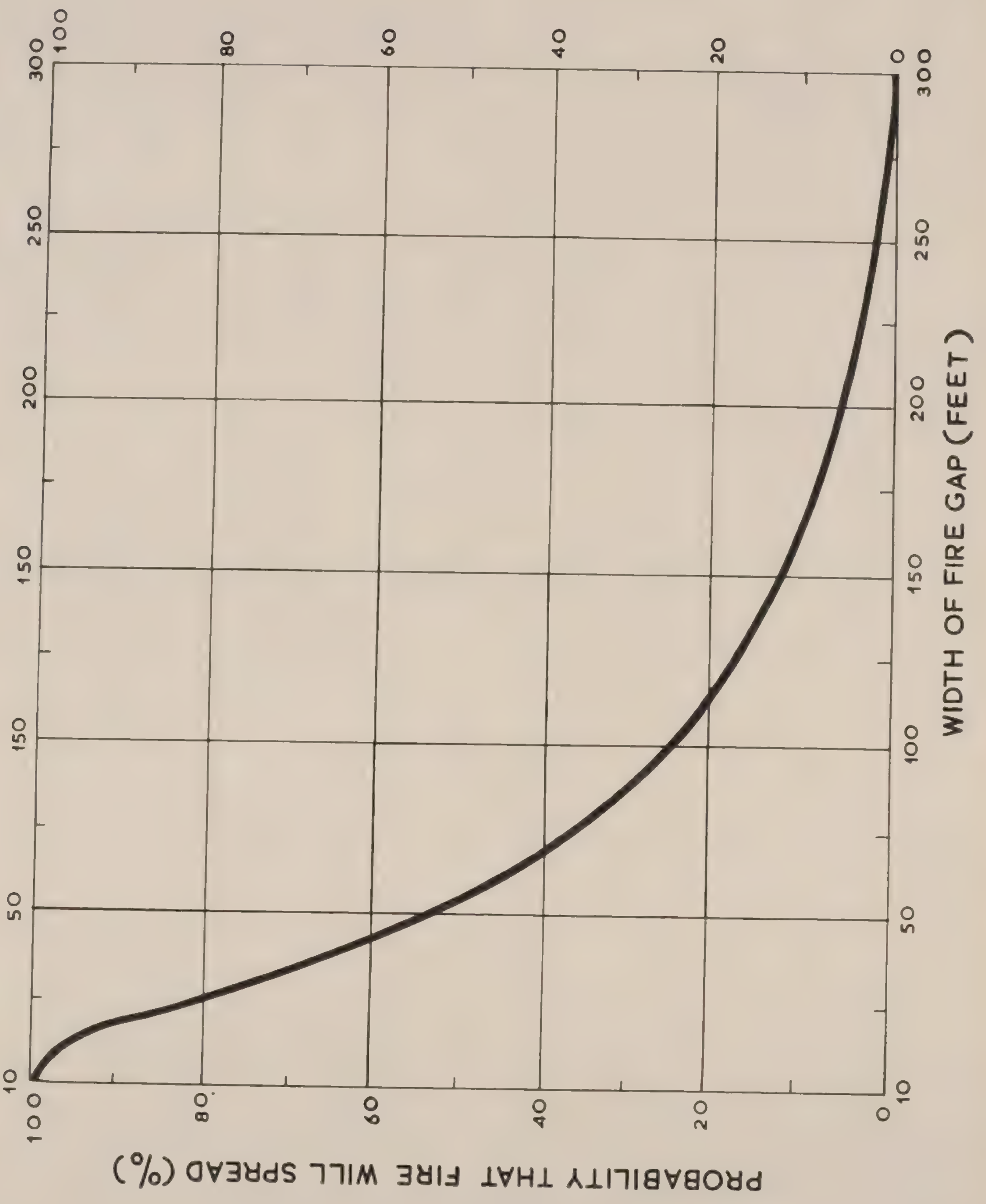
(iii) They are a guide for those concerned with the problems of shelter and evacuation.

The curve in Figure 1 gives a rough idea of how the probability of fire spread, expressed as a percentage, depends upon the average distance between buildings in a city. (Reference (1), p.321). The results will be dependent, to some extent, upon the types of structures involved, e.g. whether they are fire-resistive or not, as well as upon the damage caused by the blast wave. It should be noted that Figure 1 applies to fire spread accompanying a nuclear explosion, when a large number of small fires are started directly by thermal radiation and indirectly in other ways.

References

(1) Effects of Nuclear Weapons, U.S.A.E.C., 1957.

(2) Home Office Report CD/SA.21. "The Zoning of Towns for Fire Susceptibility". (Secret).



PROBABILITY OF FIRE SPREAD ACROSS
GAPS IN BUILT-UP AREAS

6.3. Fire Control

From what has already been said about the scope of fire storms and conflagrations, it is obvious that much fire control action must be taken prior to the start of the fire. An important first step is, of course, the elimination of all exposed kindling fuel, either by removal of the fuel or by shielding it from exposure to a thermal flash. A second important step is the elimination or dispersal of all combustible materials. Some other factors which may influence fire control will now be considered.

(i) Effect of weather

The weather, prior to and during the detonation of a nuclear weapon, will have an influence on fire control and, in the case of grass, brush and woodland fires, information concerning weather conditions is useful in evaluating probable fire behaviour. (For details of thermal damage to vegetation see Chapter 5.). Based upon weather conditions, four classes of burning potential are recognised - low, moderate, dangerous and critical. These burning potential classes, and the probable fire effects of each, are shown in Table 1, taken from Reference (1).

/Table 1

Table I - Burning Potential and Fire Effects

Burning Potential	Type and Rate of Spread	Civil Defence Requirements
Low	Slow burning fires, no spotting	No direct danger; fire can be controlled at will; control action can be on an individual structure basis. Organised action needed to corral fire and confine to area originally ignited.
Moderate	Fires burn rapidly, individual building fires combine to form an area fire	ditto
Dangerous	Fast-moving fires which spread readily over large areas and throw spot fires ahead $\frac{1}{4}$ to $\frac{1}{2}$ mile	Probability of mass damage high. Aggressive, organised action of all available personnel and equipment is essential to limit mass damage.
Critical	Conflagration-type, fast-moving fire fronts and fire storm highly probable.	Personnel and equipment should be evacuated from in front and from near the flanks of such fires. Organised action only on rear and flanks with plants to attack head when changes in fuel or burning conditions permit.

The effects of wind and relative humidity on the burning potential have been roughly integrated into Tables 2 and 3.

Table 2 - Burning Potential in Relation to Relative Humidity and Wind - Level Terrain (slopes less than 20 per cent)

Wind Velocity at 20ft. Above Ground (m/hr)	Relative Humidity			
	Above 40	26 to 40	15 to 25	Below 15
0 to 12	Low	Moderate	Moderate	Dangerous
13 to 24	Moderate	Dangerous	Dangerous	Critical
Above 24	Dangerous	Dangerous	Critical	Critical

Table 3 - Burning Potential in Relation to Relative Humidity and Wind - Steep Terrain (slopes greater than 20 per cent)

Wind Velocity at 20ft. Above Ground (m/hr)	Above 40	26 to 40	15 to 25	Below 15
0 to 12	Moderate	Moderate	Dangerous	Critical
13 to 24	Dangerous	Dangerous	Critical	Critical
Above 24	Critical	Critical	Critical	Critical

As may be seen from these Tables, the presence of a strong wind is of prime importance in assessing the burning potential. In the case of the mass fires expected in atomic attacks, strong fire winds will probably assure the existence of wind velocities much greater than 24 miles per hr. The presence of prior strong winds however, will be important in determining whether the mass fire will be of the fire storm or conflagration variety. With the exception of these wind effects, weather does not play as large a role in fire effects of atomic attacks as has been frequently assumed. Clouds, fog and precipitation may influence the extent of fire damage by attenuating the thermal radiation pulse (for details see Section 1.2.2. of Chapter 1), and also by creating conditions favourable to the high moisture content of fuels. However, the kindling fuels are quite thin and respond rapidly to changes in humidity. Thus a very short period of sunshine is sufficient even after heavy rain, to dry out many of these fuels. In fact, the energy in the thermal pulse itself is frequently sufficient to dry out and then ignite the kindling fuel at only a slightly higher calorific level than would have been required had the fuel been dry.

Once a good fire has been started, it can readily overcome the retarding effect of moisture in heavier fuels. Therefore high humidity during the period preceding the attack is important only in the initial stages of the fire. If this obstacle to fire initiation is overcome, humidity will be of minor importance in retarding fire propagation and spread. In fact, studies conducted during the last war indicate that even when rain was falling, during conventional fire bomb attacks, the damage produced averaged only 20 per cent less than that produced under weather conditions favourable to the attack, (Reference (1)).

In the case of atomic attack, a heavy rainfall during the attack period will be extremely effective in reducing ignitions in kindling fuels exposed to the weather, but will not noticeably alter the ease of ignition of protected materials inside a building. The outer walls of buildings if soaked with moisture, will resist fire spread longer, and give time for organised fire defences to act. Snow does not hamper the spread of fire to the same extent as does rainfall, because the side walls of buildings do not become water-soaked. Snow on the roof, if melted by a fire, tends to run off through channels without wetting down the walls to any great extent.

(ii) Water Supplies

Sprinkler systems have been highly successful in the past in combating conventional fires. However, they usually only cover the contents of buildings; they are not activated until fires have had an opportunity to become established; and they operate at a capacity inadequate to handle a large scale disaster. Sprinkler systems as they are now used are designed to handle the opening of a small fraction of the sprinkler heads in any one building at any one time. Neither the water supply nor the piping system permits simultaneous operation of any large number of sprinklers without extreme loss in effectiveness. Thus the opening of a large number of sprinkler heads by the widespread fires resulting from atomic attack would most probably limit the output at each head to a mere trickle.

Failure of water systems during atomic attack is to be expected, not only for sprinkler systems, but for practically all types of conventional fire-fighting methods. Thus at Hiroshima, for example, even though the water reservoir was undamaged, 70,000 breaks of pipe connections in buildings and dwellings were caused by blast and fire effects, and consequently the pressure in the mains dropped to zero. Even when the water system is not disrupted, experience in fighting war time mass fires in the past has indicated that a professional Fire Department using conventional technique is useless except on the fringes of the fire (Reference (1))

Much of the fire-fighting equipment has been lost in an attack; debris-littered streets have prevented the entry of fire-fighting equipment where it was needed; strong fire winds have made even motion next to impossible; and failure of communication systems has led to almost complete confusion.

Where a built-up area adjoins a large body of water, use may be made of an item of fire-fighting equipment which appears to provide the best chance of surviving an attack and being utilised in subsequent fire-fighting action - the fire boat. It is equipped with its own pumping facilities, is flexible in its uses, and may be moved anywhere along the waterfront area where it can be effectively used. Another conveyance which is extremely useful in mass fire situations is the helicopter. Its use for rapid reconnaissance of the fire area is obvious and in addition, recent work has indicated its great potential as a carrier of water, chemicals and equipment in perimeter fighting of large-scale forest fires. (Reference (1)).

(iii) "First Aid" Fire Fighting

Most ignitions by thermal radiation are quite small and readily extinguishable if caught early; they are serious because there are so many of them. In the initial phases, these fires may be extinguished with minimal equipment. They may be stamped out by foot or dealt with by conventional fire extinguishers. Where the number of primary ignitions is relatively small, and sufficient manpower is available for prompt action, the subsequent spread of fire from a doomed area may be prevented. Similar techniques would be useful in fighting the spot fires started by firebrands which may jump fire breaks.

(iv) Flame-Retardant Treatments

The treatment commonly applied to materials to reduce the fire hazard may be divided into two categories - surface treatments and impregnation treatments. In choosing a particular treatment, matters other than their efficiency as fire retardants must be considered. For example, few treatments are suitable in exterior conditions, so that normally only interior combustibles can be treated, and even then many treatments affect the working qualities of timber or corrode metal fastenings.

Some paints, based on urea formaldehyde resins and monoammonium phosphate, when exposed to heat, bubble up to form an aerated non-flammable coating of low thermal conductivity which protects the material for some time. Other paints, such as those based on sodium silicate, give protection by providing a vapour proof membrane round the material. In the same class are those which use an incombustible insulating material such as asbestos or mineral wool. These are usually mixed with a binding solution and applied in a thick layer. A thin layer of asbestos paper completely covering the combustible material, is probably as effective as many of the best paints. A different type of protection is given by paints of the calcium sulphate type which hold the temperature of the material at 100°C until their water of crystallisation has been removed.

To impregnate timber, a number of salts may be used. The most efficient and also the most commonly used salt is monoammonium phosphate; others are boric acid, ammonium chloride, ammonium sulphate, magnesium chloride, and zinc chloride. Ordinary white distemper is quite effective in delaying ignition, doubling the quantity of heat required for the ignition of fibre insulating board, while phosphate resin paint is even more effective. These treatments increase the difficulty of ignition and initial spread of flame, (Reference (2)).

References

(1) Report U.S.N.R.D.L., TR-101 (1955) "Thermal Vulnerability of Military Installations"

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CHAPTER 7 - BIOLOGICAL EFFECTS OF THERMAL RADIATION

7.1 Introduction

The radiant heat emitted by the air burst atomic explosions over Japan caused a large number of casualties through burns of the skin directly exposed to it; these are known as flash burns. These injuries were noted in early reports, but their importance tended to be overlooked compared to radiation sickness, until the Bikini trials. Many of the Japanese flash burn casualties died of shock or other wounds, and flash burns among survivors became grossly infected due to ignorance, and the breakdown of medical services. Consequently, survivors showed exaggerated scars (keloids). These effects, coupled with the delay before flash burn survivors were closely interrogated and examined, meant that the course of treated uninfected flash burns was unknown. The present account of the response of man to thermal radiation falling on his skin must therefore be built upon the results of subsequent experimental studies in the laboratory.

In the assessment of burn injuries, the percentage of body surface involved is important as indicating the extent to which life is threatened, particularly by "surgical shock." If over 60% of the body surface is burnt, recovery is unlikely; if under 20% of the body surface is burnt, recovery should be certain in the absence of complicating injuries. Such methods as the "Rule of Nine" (Reference (6)) are used to estimate these percentages.

Since 1949, the problems of flash burns have been reviewed (References (1), (2)) and investigated (References (3), (4), (5)). It is obviously much easier to conduct flash-burning studies on animals than on man, and a much larger number of experiments on animals have been performed. However, serious errors can arise from using the results of animal experiments to deduce effects in man. The present review (sections 7.2 to 7.7) will therefore be based as far as possible on the results of investigations of flash burns in man.

Much of the energy released in a nuclear explosion appears in the form of ultra-violet, visible and infra-red radiations. The preretinal media of the eyes, i.e. cornea, aqueous, lens and vitreous, are together opaque to ultra-violet radiations, but they do transmit most of the visible spectrum and a large part of the infra-red. Consequently, these are the radiations potentially capable of affecting the retina. In fact, the thermal radiations from a nuclear weapon may affect the eye in two ways - burns on the retina causing a permanent visual defect, and temporary flash-blindness. Burns on the retina (chorioretinal burns) are discussed in Section 7.8.1, and flash-blindness in Section 7.8.2.

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(6) The Nuclear Handbook for Instructors and Staff Officers - Page 192. War Office Code No. 9405, Air Publication AP3321. (Restricted).

7.2 Flash Burns in Man

7.2.1 Local Effects in the Skin.

As already noted in the case of materials, the thermal dose required to cause a given response in the skin depends upon the rate of delivery, being less for the faster deliveries. The doses of radiant heat considered here range up to about 5 cals/cm^2, delivered in about 0.5 seconds, characteristic of a 20 KT bomb. For doses corresponding to other durations, see Section 7.5.3. These doses would not cause burns through clothing, nor flame burns through the ignition of clothing, though such complications would arise with higher dose levels at shorter ranges. Thus, the flash burns described below would involve only uncovered skin, that is the face, neck, hands, wrists and forearms in men, and also the legs in women and children exposed directly to the heat flash and unsheltered by buildings, etc. It should be noted that there may be variations between individuals in their susceptibility to flash burning, and this is discussed later in Section 7.3.1. (d).

At considerable distances from the weapon, sensations of warmth or heat will be felt when a sufficient dose of radiant heat falls on the exposed skin. These sensations are of no serious import.

An immediate intense brief stinging pain, localised in the exposed area, will be felt when a sufficient dose of radiant heat from an atomic explosion falls on the skin. If the dose of predominantly white light is less than some 1.5 cals/cm^2, no signs of burning will follow. As the range shortens and the dose approaches about 2.0 cals/cm^2, here taken as the threshold for significant first degree burns, this stinging sensation subsides and is followed after about 30 seconds by an erythema (redness) of the exposed area, together with the changes listed below.

(a) 1st Degree Flash Burns (Dose 2-3 Cals/cm^2 in 0.5 seconds)

The erythema increases for about an hour. It is by then surrounded by a flare, that is a pinkness of the skin induced by local nerve stimulation, which extends for about 2 cm. beyond the edge of the burned area. There is a dull burning pain, and the flare persists from a few minutes up to several hours. The burning pain is felt for up to 24 hours.

After the first day the burned area remains reddened and sore to touch, for as long as eight days. Peeling of the fine flakes of skin epidermis (superficial skin layers) follows, and during the next few weeks the burned area becomes pigmented. Such burns do not disable seriously, but involvement of the hands would impair efficiency for manual tasks.

(b) 2nd degree flash burns - (shallow partial skin loss flash burns - typical dose approximately 3-4 cals/cm^2 in 0.5 secs)

In these burns the changes are at first similar to those for the slighter first degree burns, except that the skin is discoloured by singed hair, and the dull burning pain is more intense.

By one hour after burning, oedema is visible, localized to the exposed area. By two to thirty hours, depending in part upon environmental conditions, the burned area blisters. The blisters ache and ooze serum for three to four days, after which the burn is covered by a dry scab. This separates after

/about

a week providing infection has been excluded, otherwise the burned area shows pus. If the burn is uninfected, dilated blood vessels, filled with cyanotic (blue) blood, are visible after the scab has been removed.

In such burns, healing (in the absence of infection) takes place from the skin cells surviving deep in the hair follicles and sweat glands; thus, epithelialization (re-covering of the burn with new skin) occurs evenly from within the burned area and not from the edges. These burns are tender to pressure and are easily injured for 8-14 days. If such shallow flash burns become infected, surviving skin elements are destroyed and healing is greatly delayed; a small burn accidentally infected in the laboratory took six weeks to heal.

Incapacitation would not be complete with uninfected shallow blister flash burns unless palpebral (i.e. of eyelids) oedema and oozing interfered with vision. Oedema of the face and lips might necessitate a liquid diet. Manual dexterity would be restricted by such burns of the hand. During the first one or two days the burning pain of such flash burns over extensive areas would be distracting. It seems to have been this sensation which led Japanese casualties to apply compresses to their burns in search of relief.

(c) Second degree flash burns (deep, partial skin loss flash burns, typical dose 4-5 cals/cm^2 in 0.5 seconds.)

Nearer to the explosion, closing to the range of 3rd degree flash burns (see below), the radiant heat falling on the skin would cause intense local vasoconstriction (shut-down of the blood vessels) with consequent blanching immediately after the explosion. The surface of these burns is anaesthetic to pinprick at this stage. The blanching gives way to erythema after about a minute, following which the cource is essentially similar to that described above for shallower 2nd degree flash burns, except that, even in the absence of infection, healing is not secure until three to four weeks. Incapacitation would be correspondingly prolonged.

(d) Third degree flash burns (whole skin-loss flash burns, typical dose over 5 cals/cm^2 in 0.5 seconds)

Closer to the explosion, those parts of the exposed skin which suffer normally incident or nearly normally incident thermal radiation, would be injured to such a depth that no skin cells would survive deep in the hair follicles or sweat glands. Under these circumstances, the skin cannot heal itself except by growth for short distances from the surviving edges. The importance of this state of affairs is that scars will inevitably form over burned areas. Such scars, months or years later, contract and become hard, both of which tendencies prevent normal movement and proper function of skin and joints. It is to avoid this scarring that modern treatment covers the burned areas with skin grafts, whose growth inhibits scar formation beneath them.

In 3rd degree flash burns, the brief stinging pain is also followed by blanching. The margins of the burned area pucker due to the contraction of the burned area. The tissues below and around the burned skin swell during the next hour. This oedema lasts for two days or so. By this time, blisters have become discernible at the edge of the 3rd degree burn. The central 3rd degree burn remains sore to touch for 7 to 10 days and is tender to pressure until healed. By the fifth day after burning, the area begins to change from white to a pinkish hue. The dead burned skin spreads from the surrounding tissues during the third week and sloughs away during the fourth week. In the case of small experimental burns, healing takes place from the edges before granulations (the precursors to scars) are established at the base of the burn. It is to be expected that if such burns covered areas wider than 2 cms., sloughing would be followed by the formation of granulations. In that event, plastic surgery would be required to prevent scar formation and to restore adequate function by skin grafting. The time required for healing in such burns after an atomic bomb attack would therefore depend upon the medical and surgical resources available to treat them; the prevention of infection in such burns would enhance the chances that skin grafts would take and effect a satisfactory quick result. Infection would attack skin grafts in much the same way as it destroys surviving skin cells in hair follicles and sweat glands in shallower burns, and thereby increase the surgical procedures necessary to achieve healing.

Incapacitation from 3rd degree burns would obviously be greater and more prolonged than in shallower burns; it might include a period in a hospital. It is important to stress that, due to the curvature of the body, 3rd degree burns would be surrounded by regions of 2nd and 1st degree burning. Since there would be an additional area of flaring beyond, judgement of the extent of flash burns would be complicated.

(e) Superimposed effects on the skin

It is also to be expected that the appearance of flash burns when first seen would be masked by other effects arising from the attack; they would almost certainly be soiled by dust thrown up later by the blast wave; lacerations, bruises and abrasions might be superimposed. It seems probable that the recognition and accurate diagnoses of flash burns would be facilitated by adequate cleansing.

7.2.2 General Effects and Complications

The following are, strictly speaking, medical problems. They are considered in detail in various medical publications about flash-burning. They are mentioned here briefly to complete the description of 'target response', for this is more than skin deep in man.

(a) Early complications from burning injury - Immediately after flash-burning injury, the casualty may show one or more of a variety of reactions, so-called 'primary shock'. Some may faint or vomit. Others show symptoms of relief that they were not more seriously injured: they may show marked tremor of the hands, lips, face and even head. In the event of attack by atomic weapons, it is possible that panic may be added, especially if many fires are started or there are other startling consequences of the attack.

After a few hours, or even a day, a more serious derangement may ensue, so-called secondary shock. This is due to a reduction of the volume of fluid in the circulating system, the blood vessels. If the skin over 15-20%* of the body surface,) is burned 2nd degree or deeper, the amount of plasma lost can so deplete the blood volume as to be a threat to life. The body reaction to diminishing blood volume is, firstly, to restrict the circulation to the hands, feet, nose and ears, which consequently feel cool compared to the rest of the body (N.B. they may feel cool in people lying in a cold environment). Next, the pulse quickens. If these measures fail to compensate for the plasma lost, the blood pressure will fall. The blood passing the kidneys is presently reduced, so that little or no urine is formed, and if the process continues, the mind becomes clouded with restlessness and coma unless treatment is instituted. All these changes can be reversed by adequate therapy; without therapy, death may ensue.

There is ample evidence from eye-witness accounts that this chain of events occurred among Japanese casualties. This may have been due to the scanty clothing worn by the population. But since a flash burn of a man in singlet and shorts would involve over 15% of his skin (or more if the prolonged flash from a larger weapon resulted in flash-burning of all unclothed skin), such a casualty would be likely to require special resuscitation and perhaps intravenous transfusion therapy.

(b) Later complications from burning injury - The later complications are usually the results of inadequate medical attention. Flash burns easily become infected. The body responds by making white cells (pus); again there is ample evidence that this occurred in Japan. The formation of large quantities of pus leads to a debility (from protein deficiency). The patients become anaemic and more susceptible to infection, so that a vicious cycle sets in causing very prolonged incapacitation and a poorer prognosis. These complications are prevented by excluding infection. It is possible, but more difficult and more expensive, to treat infections with drugs and antibiotics after they are established.

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*This is roughly equivalent to flash-burning a man in singlet and shorts.

The late complications of burns are scarring and the contraction of scars. These may take years to develop. The contracted scar can so impede movement as to cripple the patient. Such complications can be prevented by early skin grafting, or treated by exclusive plastic surgery. Again, late treatment is rarely as satisfactory as prevention.

(c) Injuries in addition to flash-burning - There remains also the possibility that flash burns may be complicated by other injuries. The casualty who has suffered a flash burn may receive a laceration, contusion, abrasion, fracture or penetrating wound as a result of the blast wave arriving a few moments later. Or, if the flash burn casualty is at a shorter range, or trapped in a burning building, he may have additional burns from ignited clothing or contact with both objects during his escape. Finally, under various circumstances, the flash-burned casualty may also suffer a serious dose of ionizing radiation. In a study of anaesthetised dogs, burned and irradiated with various doses of X-rays, it has been found that small doses of radiation (50r) made the animals more susceptible to infection in their flash burns. This could be counteracted by suitable antibiotic therapy. (See also Part VII, Chapter 2, Section 2.1).

7.3 Threshold Doses for Flash Burns

7.3.1 Factors Influencing Thermal Effects

Through knowledge of the threshold doses required to produce them, the range of the local effects in the skin (See Section 7.2.1) can be deduced from the thermal doses received from atomic explosions. These thresholds, and the parameters mentioned below, have been studied in various laboratories (e.g. References (1), (2) and (3)). The local changes described are consequent upon physical and chemical effects brought about in the superficial layers of the skin by the incident energy. The following factors may influence these effects.

(a) Spectral qualities of the incident radiation - Briefly, ultra-violet light (U.V.L.) is absorbed exclusively in the most superficial layers of the skin. Here it causes photo-chemical changes and the release of substances which produce reddening and blistering of the skin (cf. sunburn). It is unlikely that U.V.L. is important in flash-burning from atomic weapons since calculations indicate that it is absorbed by the atmosphere in comparatively short distances. Of visible light (V.L.) incident on the skin, about 50% is reflected. Some wavelengths in the visible band penetrate deeper in the tissues than U.V.L. or infra-red radiation (I.R.R.). The skin reflects about 10% of incident I.R.R., most of which is absorbed in the first 2 mm. of the tissues.

(b) Area of exposure - One of the problems in studying thresholds in the laboratory was selecting an aperture-size large enough to permit extrapolation to burns as large as the face or forearm and small enough to be acceptable for volunteers. In a study designed to investigate this point (Reference (4)), it was shown that in the case of 2nd and 3rd degree burns apertures 1 cm. in diameter provided a reasonably reliable basis for the thresholds which would obtain if larger areas were exposed. This was not true for sensations of warmth, heat and pain, and for 1st degree flash burns, for which endpoints it was found that increasing the area exposed reduced the threshold dose per unit area required to elicit the response. However, these latter endpoints have no serious clinical consequences (general effects), so that the area-dependence of thresholds is of more academic than practical importance.

(c) Duration of exposure - This is discussed later in connection with scaling laws (Section 7.5.3). The question has not been thoroughly investigated in man for reasons given there, but the effect of duration of exposure is regarded as negligible between the limits 0.3 and 1.0 seconds. It should be noted however that for a given thermal dose, as the weapon yield increases, the thermal radiation is delivered over a longer period of time and thus at a lower rate. This allows energy loss from the skin surface by conduction to the deeper layers of the skin and by convection to the air. Thus a given level of damage is also yield dependent. Critical radiant exposures for the production of two degrees of burn on bare skin, as a function of yield, are presented in Figure 1 (taken from Reference (5)) for

/normal

normal incidence of radiation. The curves represent those radiant exposures which will burn 50% of any group, allowing for the other variants discussed in this section.

(d) Individual variations in skin temperature, reflectivity, thickness, texture and hairiness

It is known that the local effects brought about by visible and infra red radiation are temperature dependent, because the threshold doses can be raised by artificially cooling the skin before experimental exposures. This factor might double the threshold doses for second degree burns in very cold conditions.

Variations in skin reflectivity are of more importance as between races than between individuals of like race. There is evidence that the dark-skinned races are more susceptible to flash burning than the white (guess 2:3), (Reference (6)).

All investigators have noted that the thicker coarser skin of males is slightly more resistant to flash burning than that of females. Children have not been studied and the effect of age is not known.

In Japan it was unusual for flash burning to occur through the hair of the head. However there is as yet no experimental evidence that the hairiness which occurs over the forearms affords any significant protection.

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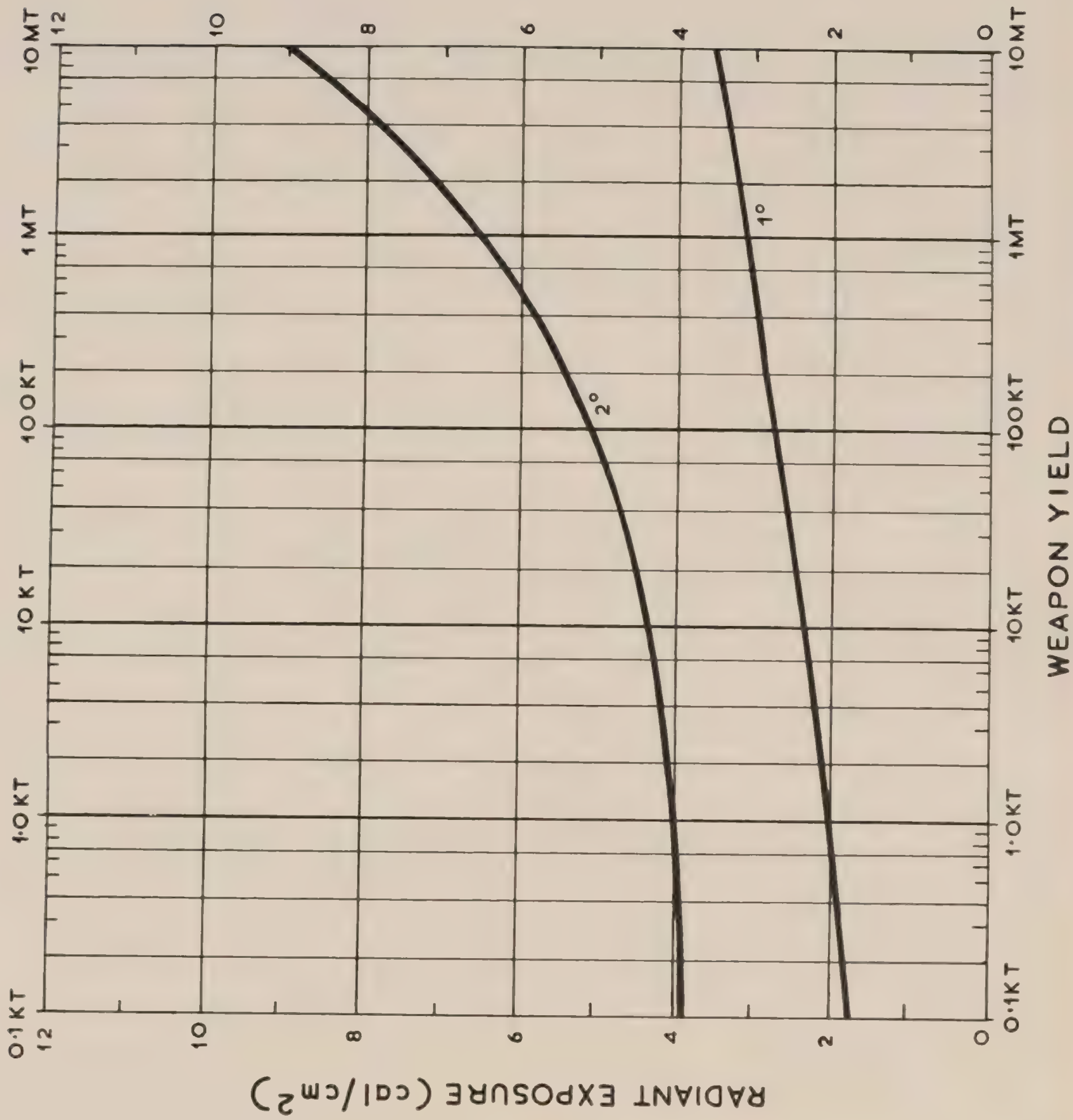

CRITICAL RADIANT EXPOSURE FOR 1ST AND 2ND DEGREE BURNS ON BARE SKIN

7.3.2 Laboratory Studies of Threshold Doses

The results of some laboratory investigations (References (1), (2) and (3)) into threshold doses for various effects, are given in Table 1. Essential details of the experimental methods are also given.

TABLE 1 - 50% Probability Threshold Doses (Cals/cm^2)

Key to Exptl. Methods (See below)	Thermal Radiation Type	Aperture Diameter cm.	Exposure Time secs.	Dose in Cals/cm^2				
				Pain	1st Degree Flash-burns	2nd Degree Flashburns Shallow	2nd Degree Flashburns Deep	3rd Degree Flash-burns
(i)	IRR	5	1.0	<0.7	< 1.5	2.1	-	-
		3	1.0	0.75	1.5	2.1	-	-
		1	1.0	>0.8	> 1.5	2.1	-	-
(ii)	(Predominantly Visible)	1	0.17-0.45	-	2.0	3.0	4.0	5.25
(iii)	(")	1.8	0.3	-	1.3	2.8-3.2	-	<<8
(iv)	VL & IRR	1.1	0.54	-	2.0	3.2	3.9	4.2

(a) Experimental methods

(i) Source - Gas-fired radiant panel, surface temperature 1000°C. The emission spectrum is shown in Figure 1A together with curves for transmission of skin surface and penetration beyond 2mm.

Calibration - Copper block and special radiometer.

Subjects - 8 males, 20-32 years of age. Site - Forearms. Unshaven skin.

(ii) Source - Unfiltered beam from carbon arc. The emission spectrum is shown in Figure 1B together with curves for transmission of skin surface and penetration beyond 2 mm. Squarewave input.

Calibration - Copper block and bolometer.

Subjects - 7 males, 20-32 years of age. Sites - Forearms and wrists. Unshaven skin.

(iii) Source - Unfiltered beam from carbon arc. Squarewave input.

Calibration - Copper disc and special radiometer.

Subjects - 7 males. Sites - Arms and legs.

(iv) Source - Carbon arc, UVL filtered off by Corning Filter 0-53 with cut off below 3200A. Pulse form input.

Calibration - Flow calorimeter and copper disc.

Subjects - 12 males, 2 females. Site - Outer aspects, shoulders and upper arms.

(b) Conclusions

There is good agreement between the various investigators using carbon arc sources. The IR results quoted are the only data available from investigations using an IR source: experiments using filtered beams from carbon arc must be regarded as less reliable due to the impossibility of accurate calibration before the filters are destroyed by heat.

The IR threshold doses are lower than the predominantly VL threshold doses, in the ratio of about 2:3. This can be accounted for by differences in spectral quality, skin reflectances and absorption. Calculations show that the energy absorbed between the skin surface and a depth of 2 mm. would be approximately the same in both series of burns.

Bearing in mind the area dependence of threshold doses per unit area for pain and first degree flash burns, the following may be regarded as best estimates available for threshold doses for 50% probability of various severities of flash-burning for young men.

		IRR		Predominantly VL	
		(Source = 1000°C)		Source about 5000°C	
Pain		0.7	cals/cm^2	(1.0)	cals/cm^2
1st degree flash burns		1.5	"	2.0	"
2nd degree flash burns:	Shallow	2.0	"	3.0	"
	Deep	(2.7)	"	4.0	"
3rd degree flash burns		(3.4)	"	5.0	"

The figures quoted in parentheses have not been confirmed by experiments with volunteers.

It is probable that these thresholds are higher (perhaps by 15%) than would obtain in a population including women and children.

It will be appreciated that all flash burns of 2nd degree or worse would be at a risk from infection and cause sufficient incapacitation to demand medical attention.

Numerous thermal experiments with animals have been made in the United States, usually with Chester White pigs. The skin of the latter has a similar response to thermal stimulus causing first and second degree burns, to that of human skin. Details of some of these experiments will be found in References (3) and (4).

References

(1) Butterfield, W.J.H. et al. Flash Burns from Atomic Weapons. I. Observations on Flash-burning of Human Subjects in the Laboratory using Infra-red and Predominantly White Light Sources. Surg.Gyn.Obst. 1956. 103:655-665.

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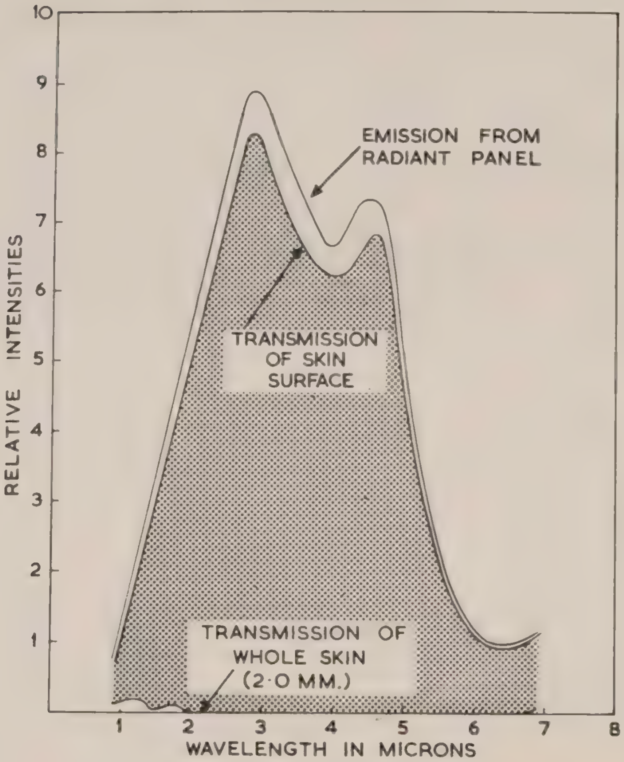


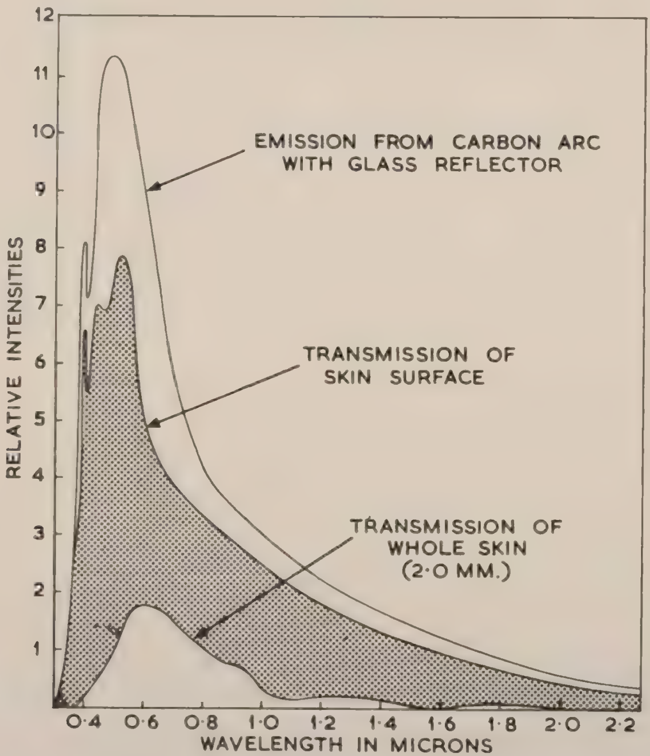
A. TRANSMISSION OF SKIN SURFACE BY INFRA RED RADIATION

FIGURES A AND B SHOW:-

1. SPECTRAL DISTRIBUTION OF RADIATION FALLING ON THE SKIN FROM:-
   A. INFRA RED SOURCE
   B. WHITE LIGHT SOURCE
2. TRANSMISSION OF THE SKIN SURFACE.
3. PENETRATION BEYOND 2 MM. DEPTH INTO SKIN.

THE AREA BETWEEN TOP AND MIDDLE CURVES OF EACH FIGURE REPRESENTS SKIN REFLECTION.

THE SHADED AREA REPRESENTS ABSORPTION IN THE SKIN, FROM SURFACE TO 2 MM. DEPTH.



B. TRANSMISSION OF SKIN SURFACE BY RADIATION FROM PREDOMINANTLY WHITE LIGHT SOURCE

7.4 Healing Times of Uninfected Flash Burns

The information about threshold doses for flash burns given in Section 7.3. provides data for predicting for Civil Defence or military purposes the ranges of flash burns and the areas wherein they may be sustained (see Section 7.5). Another important factor in this connection is the duration of incapacitation to be expected if complications, especially infection, are prevented. This factor has been investigated methodically in the case of flash burns from predominantly white light (Method (ii) Section 7.3.2), between the limits of doses of 2.0 to 5.25 cals/cm^2. Above 5.25 cals/cm^2, the healing time will be affected by the surgical resources available to treat the 3rd degree burns caused. All the experimental flash burns were kept free from infection by suitable cleansing shortly after burning and by antibiotic barrier creams and occlusive dressings, and the course followed until they were accepted as healed by five qualified observers. The criteria for healing were absence of soreness to touch or firm healing of the skin over the burn. Soreness tended to outlast firm healing in shallower burns but it was taken as a criterion because flash burns are likely to affect the hands, and soreness there would incapacitate casualties.

The relationship between the dose of incident energy per sq.cm. and the healing time for the complete series of 1 cm. diameter flash burns from predominantly white light (unfiltered beam from carbon arc.), was:

$$t = 0.92\,q^2 + 1.26q - 4.26$$

where t = healing time in days

and q = dose in cals/cm^2.

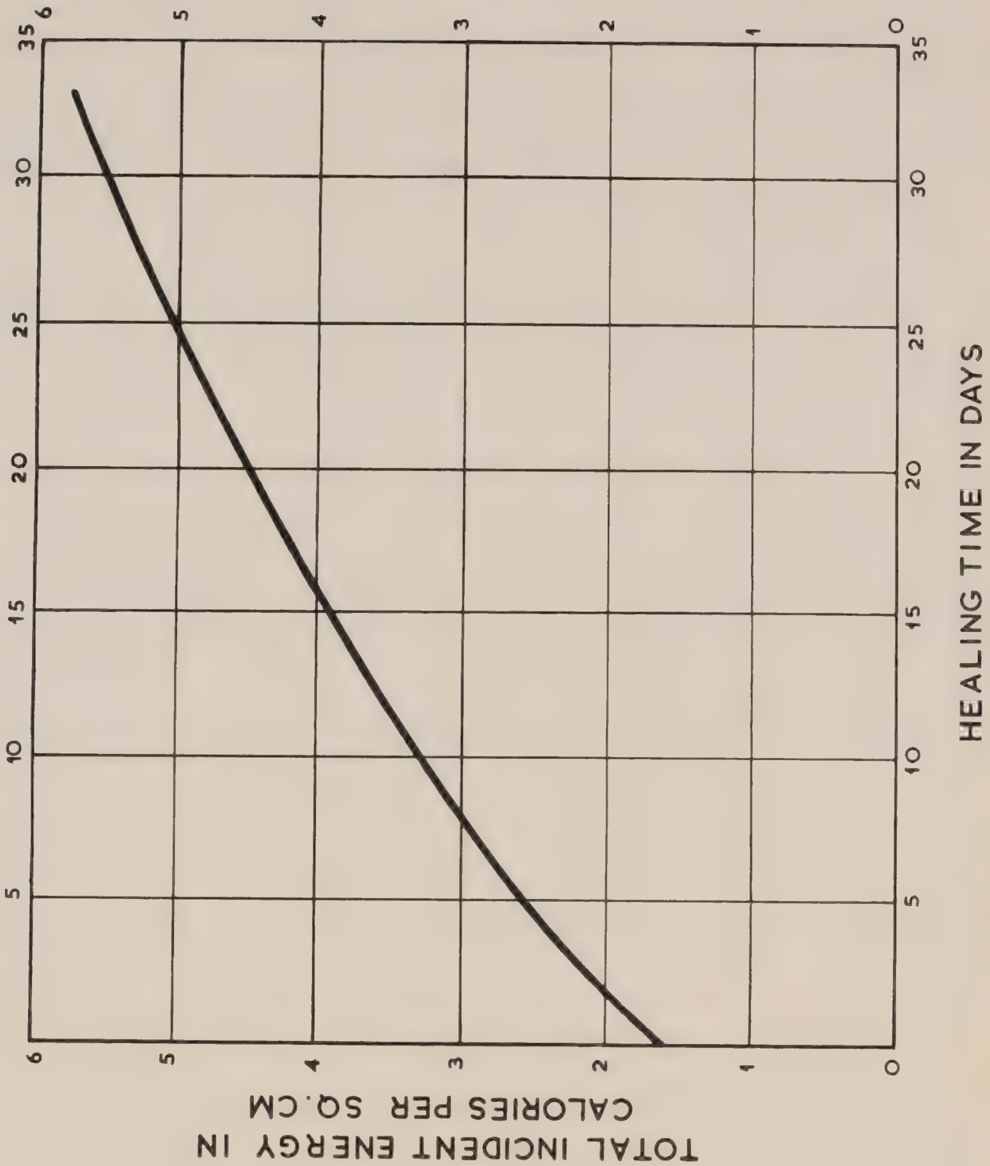
It may be noted that t becomes finite when q exceeds 1.5 cals/cm^2. When allowance is made for the area dependance of 1st degree flash burns, that the threshold is less if larger areas are exposed, it is apparent that the disability caused by 2.0 cals/cm^2 falling on the face or hand would be significant even if not warranting special medical dressings, etc. This relationship is given in graphical form in Figure 1 (from Reference (1)).

From the formula, the healing time to be expected for uninfected flash burns from 3.0, 4.0, and 5.0 cals/cm^2 of predominantly white light would be 8, 15 and 25 days respectively. These healing times would be extended by infection, which destroys the surviving skin cells thereby producing, in effect, a deeper burn. Thus, in another experiment, No. (i), Section 7.3.2, although uninfected burns healed in 12-24 days, one which was inadvertently infected required 42 days to heal.

Healing times were not studied systematically in the other investigations involving volunteers, but the qualitative statements given about healing times are in good agreement with the formula.

Reference

(1) Tripartite Conference on Effects of Atomic Weapons (1957). Paper AWEC/P(57)104 (Confidential). "Flash Burns from Atomic Weapons" by W. J. H. Butterfield and E. R. Drake-Seager.



HEALING TIME OF UNINFECTED
WHITE LIGHT FLASH BURNS
KILOTON WEAPONS

7.5. Casualty estimation

7.5.1 Flash burns

The hazard of flashburning can be estimated by calculating the threshold doses and healing times from the thermal doses received from surface of air burst atomic weapons.

The range of flash burning will increase with increasing weapon yield, and decrease with increasing atmospheric attenuation. The experimental results given in Section 7.3.2 should provide reliable data for weapons of yield up to 100 kilotons. The ranges so calculated can then be compared with those for gamma radiation injury and injury from the effects of the blast wave.

The importance of flashburning in a community can be judged best by considering the areas in which burns of various severities may arise, and by comparing these areas to those wherein other injuries may be sustained, always remembering that flashburning affects only those exposed directly to the heat flash, unshielded by buildings etc., which is by no means true of gamma and blast injuries.

The solutions to this problem for a 20 KT bomb exploded at a height of 2,000 ft. in weather with attenuation equivalent to a visibility of $12\frac{1}{2}$ miles have been calculated and are presented in Table 1 below.

Table 1

Range and Area of Injury from Specified Effects

Cause of injury	Range of injury (yards)	Area of injury (Square miles)
Gamma radiation (150r)	1,450	2.1
Blast (2.7 p.s.i.)*	3,000	9.0
3rd degree flash burns (5.0 cals/cm^2)	3,200	10
2nd degree flash burns (3.0 cals/cm^2)	4,000	16
1st degree flash burns (2.0 cals/cm^2)	4,800	23

*This range depends on whether the population takes effective cover between the flash and the arrival of the blast wave. The estimate quoted is based on Japanese experience.

All things considered, the findings in Table 1 agreed well with the events observed in Japan.

The relationship between the range of risk of flash burns and weapon yield is given graphically in Figure 1. The ground area of the annulus for risk of flash burns is a function of weapon yield as given in Figure 2. Figure 3 gives an estimate of the relationship between weapon yield and minimum manpower loss for flash burns severe enough to demand medical attention. All three Figures are taken from Reference (1).

Some figures for the percentage of non-effectives among military personnel who receive second and third degree burns have been obtained from Reference (2), and are presented in Table 2. It should be emphasised that the data in Table 2 do not indicate the percentage of target population which becomes non-effective, but refer only to the percentage of non-effectives among those personnel who actually receive burns.

Table 2

Percentage of Non-Effectives* Among Military Personnel Who Receive 2nd and 3rd Degree Burns, as a Function of Time after Detonation

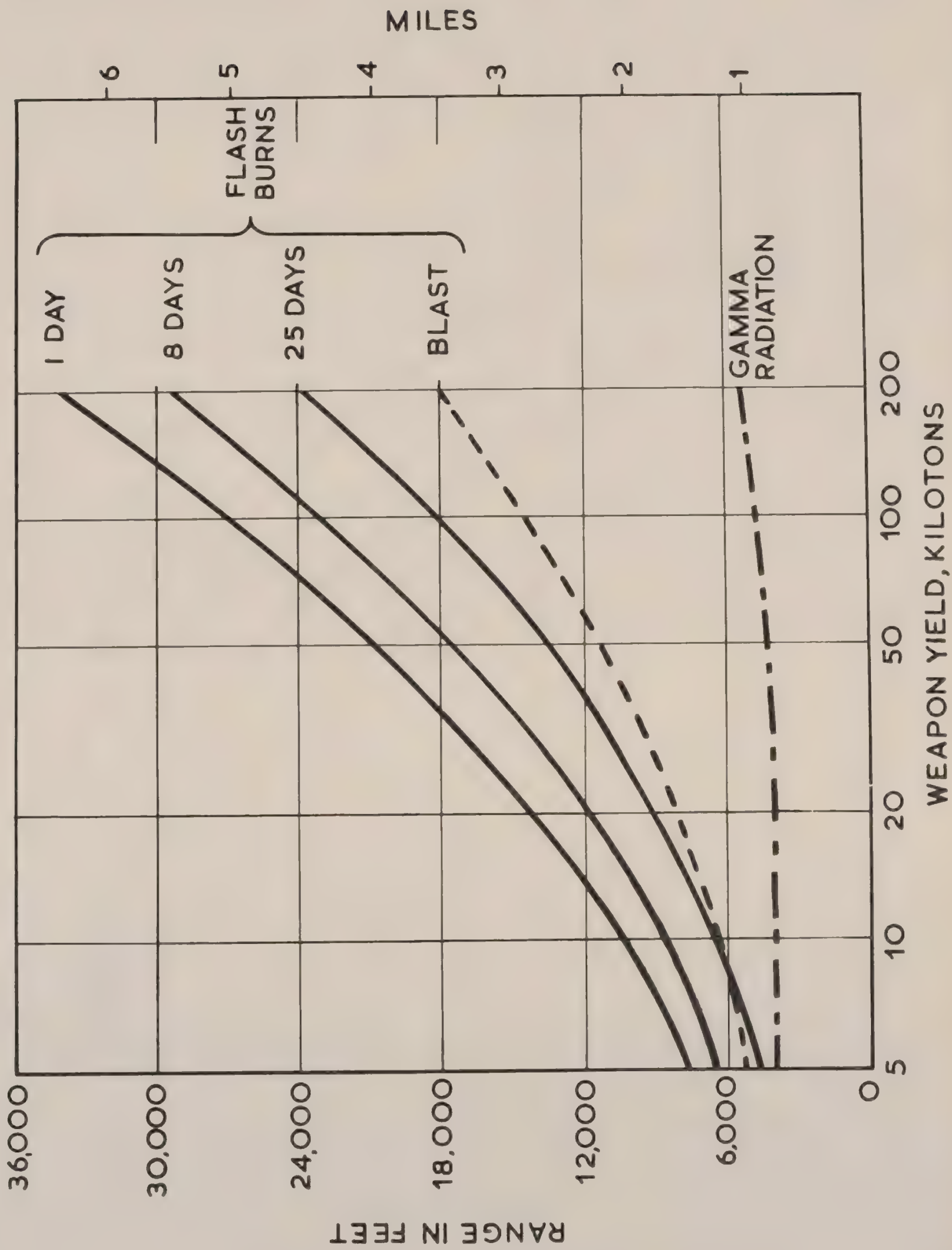
Hours after Detonation	Degree Area around both eyes burned		Degree Back of one hand burned		Degree 15% total body burned	
	2nd	3rd	2nd	3rd	2nd	3rd
0.5	10	50	8	60	10	50
1	20	100	10	30	0	55
2	40	100	30	30	0	55
3	50	100	40	30	0	55
4	60	100	50	30	5	60
5	80	100	50	40	30	80
6	100	100	50	50	50	90
24	100	100	100	100	80	100

*Note: A Non-Effective (or Combat ineffective) is defined as a person who, because of his injuries, is no longer capable of carrying out his assigned tasks. This is differentiated from the more common term "casualty" which means an individual whose injuries require medical attention.

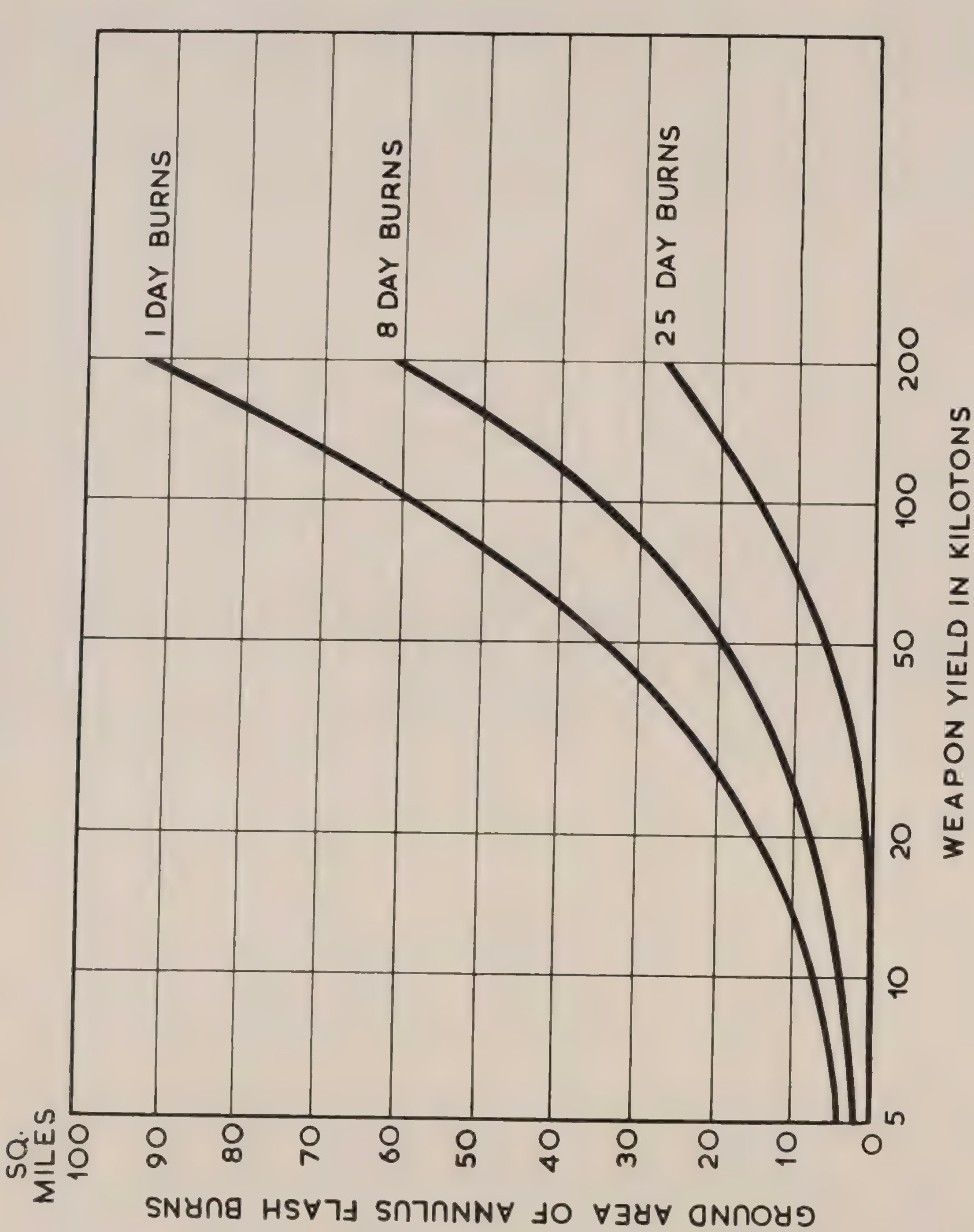
References.

(1) Tripartite Conference on the Effects of Atomic Weapons (1957) Paper AWEC/P9(57) 104 "Flash burns from atomic weapons" by W. J. H. Butterfield and E. R. Drake Seager (Confidential).

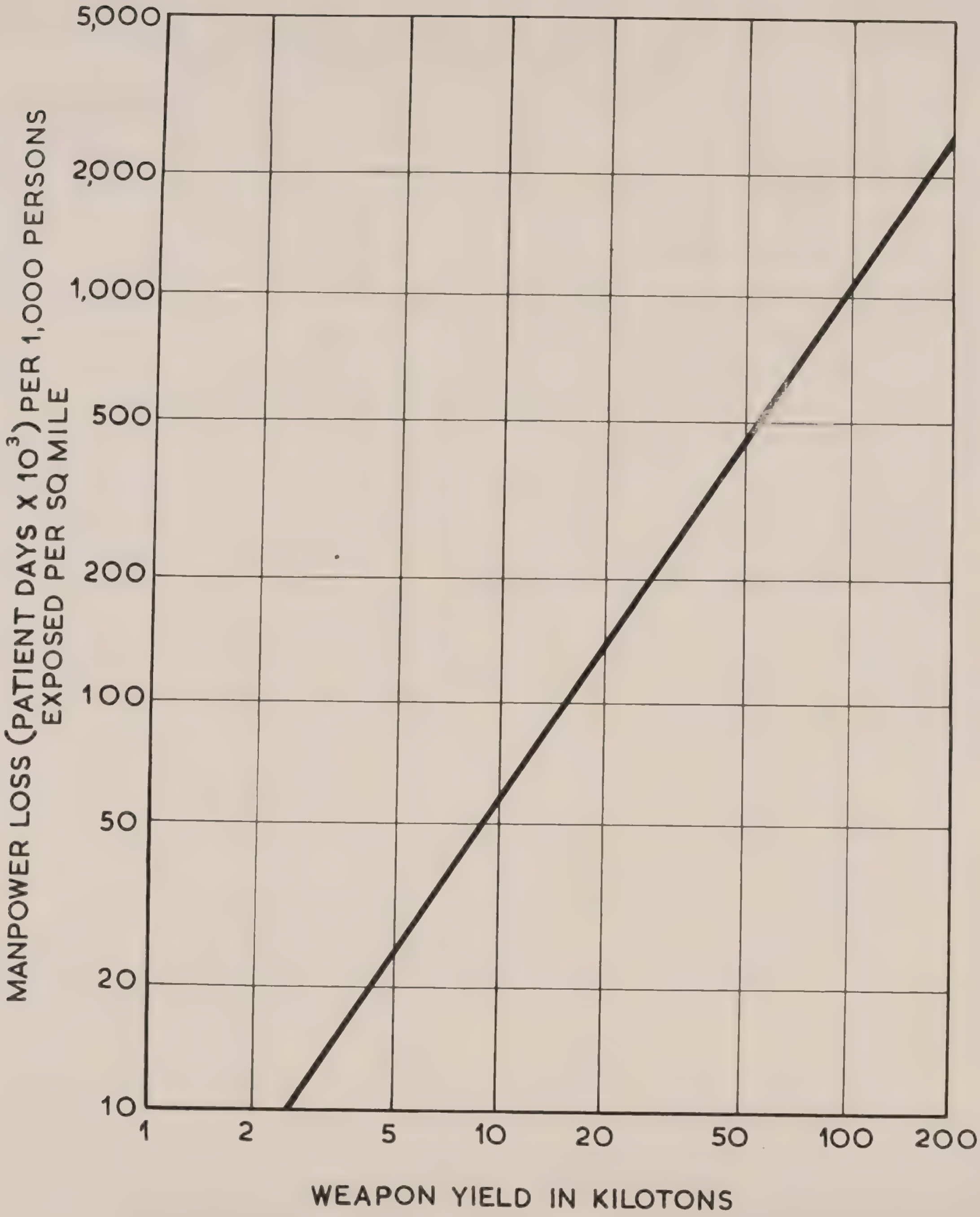
(2) Staff Officers' Field Manual - Atomic weapons employment. U.S. Dept. of the Army FM 101-31 (Secret Atomic).



RELATIONSHIP BETWEEN RANGE OF RISK OF FLASH BURNS AND WEAPON YIELD



RELATIONSHIP BETWEEN GROUND AREA OF ANNULUS FOR RISK OF UNCOMPLICATED FLASH BURNS AND WEAPON YIELD



MANPOWER LOSS FROM FLASH BURNS AS A FUNCTION OF WEAPON YIELD

7.5.2 Atmospheric Attenuation

In considering the effect of atmospheric attenuation on the range of flash-burning, it must be pointed out that atomic weapon tests have been conducted in remote places in good weather. It was assumed that the transmission of radiant heat under these circumstances would be good. It was further assumed that the transmission of radiant heat would be attenuated by the atmosphere in bad weather, with consequent shortening of the ranges of thermal effects. To calculate ranges in poor weather it was suggested that the transmission of thermal radiation be related directly to visibility. But visibility takes no account of infra-red transmission, nor does it allow for radiation scatter. Thus, while there is little doubt that rain or fog would severely curtail the transmission of the thermal radiation from an air burst weapon, there is evidence that the interaction of attenuation and scatter over the whole spectrum may mean that in dry weather transmission would, in effect, be roughly comparable to that previously quoted for a visibility of 12½ miles, irrespective of the visibility appreciated by the human eye. (See also Chapter 1, Section 1.2.2).

7.5.3 Scaling Laws

The influence of weapon yield on the range, ground area and healing times of flash burns can be worked out by making calculations similar to those shown in Section 7.5.1 for different circumstances up to the limit of 100 KT bombs.

For larger weapons, the considerations become more complex. The duration of the flash becomes an important factor. The range of flash-burning cannot be estimated accurately until it is decided what period of time from the start of the flash should be allowed for casualties to take evasive action. Anyone who has volunteered for flash-burning experiments or focussed a burning glass upon his skin will know the quickness of the response to the painful stimulus of intense radiant heat. Although the physical measurements at trial explosions indicate that 70% of the total radiant heat from a 20 KT weapon is released in 0.5 seconds, the biological evidence from the Japanese survivors and subsequent animal experiments at weapon trials suggest that physiological responses, flash burns, were inflicted in a briefer period. Remarkable shadow effects were observed among the Japanese casualties moving at the moment of detonation. This discrepancy between biological effect and physical measurement has not been adequately explained.

It would seem unlikely that the population attacked would remain stationary for exposures of over 1.0 seconds while sustaining burns: they might not suffer pain during the first half of the exposure, but experience indicates that they would not keep still for the next half second after feeling stinging pain. If the flash continues for a longer period, the motion of the population trying to evade painful burning could bring them to expose again the area originally facing the fireball. Thus, although there has been considerable study of the change of threshold dose for 2nd degree flash burns of anaesthetised pigs for exposure times from 0.3 to 30 seconds, the formula derived* is hardly applicable to conscious man.

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* $Q_c = 3.73t^{0.224}$ where Q_c = Heat dose (total) cals/cm^2 and

t = time in seconds. See Reference (3) data sheet 6a.2.

Again, it has been shown that 4.8 cals/cm^2 given as a pulse simulating the heat flash from a 20-kiloton weapon and lasting 0.54 seconds, caused a 2nd to 3rd degree flash burn, whereas a pulse lasting 2.2 seconds caused a superficial 2nd degree flash burn, and a pulse lasting 3.4 seconds caused only a 1st degree flash burn in man. However, before assuming that an extension of the duration of the heat flash by a factor of nearly 7 (0.54 to 3.4 seconds) would approximately halve its burning effect, it must be noted that the pulses were achieved by slowing the venetian-blind mechanism used, i.e. the longer pulses were not designed to simulate the heat flash from large weapons.

The information in Table 1 below, on the thermal doses causing burns to bare skin for various weapon yields, has been obtained from References (1) and (2). Some results with animals are quoted in Reference (3). A graph showing critical radiant exposures for first and second degree burns to bare skin, as a function of weapon yield, has been given in Figure 1 of Section 7.3.1. Attention is also drawn to the Target Damage Charts given in Part I. In using these data for the estimation of burns from high yield weapons the limitations discussed above should be kept in mind.

Table 1

Damage Criteria for Burns to Bare Skin (cals/cm^2)

	Weapon Yield		
	1 KT	100 KT	10 MT
1st degree	2	2.7	3.5
2nd degree	4	5.5	7
3rd degree	6	8	11

References

(1) Staff Officers Field Manual - Atomic Weapons Employment. U.S.Dept. of the Army FM 101-31 (1956) p.71. (Secret Atomic)

(2) Capabilities of Atomic Weapons - U.S. Dept. of the Army, FM 23-200 (1957) p.6-14 (Confidential)

(3) The Thermal Data Handbook. A.F.S.W.P. - 700. Sanitized Edition. 1954. (Confidential).

7.6 Diagnosis and Treatment of Flash Burns

7.6.1 Diagnosis

The recognition of the parchment-like skin, denuded of hairs by singeing, in severe (3rd degree) flash burns, presents no problems once the skin has been cleansed. In more severe burns the skin may be charred. The vivid reddening of slight (1st degree) flash burns is easily recognised. Brief mention must however, be made of the possible errors from hasty diagnosis in blister (2nd degree) flash burns. In the early stages, these injuries show vivid erythema, and if seen less than an hour after infliction no oedema would be discernible. This means that blistering may have to be suspected in all 1st degree burns seen immediately after an attack, with consequent administrative problems. After one hour, or perhaps longer in cold environments where the development of local changes may be delayed by the coolness of the skin, the presence of oedema (swelling) in the burned area must be taken as presumptive evidence that blistering will occur later, so that such cases were better treated to exclude infection.

7.6.2 Treatment

It is now widely recognised by the medical profession that the treatment of flash burns after atomic explosions presents several important features. History has shown that the proper hospital treatment of one hundred or so severely burned casualties presents the medical services, even in peace conditions, with a particularly heavy burden. It has been shown in Section 7.5 that the number of such flash burn casualties after an atomic bomb attack would be very large, especially if the community were not warned, or did not heed warning. It can be calculated from the formula for healing times quoted earlier that the minimum economic burden from 2nd and 3rd degree flash burns after the explosion of the nominal atomic bomb under the circumstances mentioned earlier would be 52,000 man-days per 1,000 persons flash-burned. Simple extensions of this calculation also show that unless such cases were treated, the complications of infection and scarring would result in even heavier long-term burdens on the community as a result of neglect. As a conservative estimate, the previous figure for man-days lost would be raised in the absence of treatment by a factor of 3. Thus treatment under the circumstances considered would save about 100,000 man-days per 1,000 persons flash-burned. The gains from mass treatment are therefore clear. The object of mass treatment would be to provide, as far as possible, the following benefits to each casualty needing one or more of them.

(a) Local treatment - Specific - There is no known specific local treatment for flash burns. Impressed by the possibility that the slow progression of events in shallow blister-burns might be due to noxious substances diffusing downwards from the superficial layers of the skin, Butterfield investigated various measures which might interfere with the process. None of the remedies he tried altered the sequence of events in the burned area.

(b) Local treatment - Early preventative - As a general rule, any flash burn showing blistering or blanching of the skin will require treatment to prevent local infection. The exact methods used to exclude infection from the flash burn will obviously depend upon the resources available, the judgment of the medical attendant, and the man-power available to effect therapy.

(c) General treatment - Early - In those cases where (2nd or 3rd degree) flash-burning is extensive, or where other burning injuries complicate flash-burning so that the total burned area is extensive, means should be found to combat circulation changes by restoring the circulating blood volume. This may be done by oral fluids, e.g. slightly salt water or in larger burns by intravenous therapy. Again, many exigencies will dictate the treatment given.

(d) Local treatment - Late - In the case of extensive 3rd degree flash burns, or 2nd degree flash burns which have deteriorated to a similar depth of injury through infection, plastic surgery will be required to restore adequate function. This may be followed by rehabilitation, exercises etc., later.

(e) General treatment - Late - Those flash burn casualties who require more than a single plastic surgical operation to repair their wounds will almost certainly require extra supportive therapy - special diets and blood transfusions.

7.7 The Prevention of Flash Burns

The methods of reducing flash-burning risks if atomic or thermonuclear warfare seemed imminent may be summarised as follows:-

(a) Dispersion of the population in space and time - Flash-burning is a daytime and especially a "rush-hour" hazard. Any policy designed to reduce the number of persons likely to be outdoors exposed to attack from moment to moment would reduce the risk to the community as a whole.

(b) Warning - Sufficient warning might be given to permit all but essential personnel to seek cover or air raid shelters. This might be difficult for armed forces in the field. With civilian communities, the problem would be that, in the presence of weapons of mass destruction, all warnings would have to be heeded. This would obviously raise serious problems of production and questions of strategy.

(c) Personal protection - For those whose duties placed them out of doors in a position of risk, or for all citizens in the event of a breakdown of warning vigilance, suitable clothing, covering as much of the skin as possible would offer protection. This would be of special importance if it could shield the face, ears and hands, and the legs in women and children. In this connection, it is important to bear in mind that multiple layers of clothing greatly enhance protection, that light colouring enhances protection, but that some fabrics are inflammable and therefore highly unsuitable in such circumstances. A detailed discussion of the protection afforded by clothing is given in Chapter 8.

7.8 The Ocular Hazard from a Nuclear Explosion

Introduction

The maximum dazzle effect produced by a nuclear detonation is sustained when the fireball is seen directly, that is when its image is formed on the retina. In this - the most severe case - the brightness of the source does not vary inversely as the square of the distance when atmospheric attenuation is neglected, for, although at greater distance less light is received by the retina, yet it is concentrated in a smaller retinal image which therefore maintains the same brightness irrespective of distance. The dazzle effect produced by reflected light from cloud or from other highly reflecting surfaces such as snow is affected by distance, since the light reflected by these surfaces is a factor of the light incident on them, and this varies inversely as the square of the distance of these surfaces from the source.

The effects on the retina produced by a nuclear detonation differ from those on the skin surface by virtue of the blink reflex, which acts like a shutter in front of the retina and can therefore prevent it from receiving the high intensity light for the entire duration of the explosion cycle. The exposure received by the eyes thus depends on whether the eyes have blinked and whether, having blinked, they have reopened to look again at the fireball.

The effect produced by the stimulus is therefore caused to vary, but even if the stimulus were constant and known, a number of other variables would have to be taken into account. The most fundamental of these is related to the subject's task. How much dazzle can he tolerate? At night does he require night vision, and if so how much? Has he merely to observe instruments which can be floodlit to a required level if he is dazzled? What part of his visual field is exposed to the dazzle source - his fovea or the peripheral visual field? Were his eyes moving when the flash of light was received? Was the flash received by both eyes in corresponding points of the retinae? What is the nature of his task: is it one of legibility of instrument markings, or is it from perception? What is the probability of being dazzled anyway?

These are some of the variables which have to be considered in assessing the effects upon vision of an unexpected nuclear explosion, and it will be obvious that to provide reasonably accurate quantitative data as to the effects produced in all situations is quite outside the scope of this manual.

The following section however attempts to give the reader the necessary background so that he may be able to form some judgment as to the severity of dazzle likely to be sustained. Towards this end, graphs are provided from which the expected luminance can be assessed and from which one can calculate dazzle recovery times to enable one to see a specified test at a given illumination. The reader should then be able to assess whether in the problem he is considering, the visual effects are likely to be above or below this known value.

The data which will be provided are based partly on theory, and partly on experimental work in which measurements were made of the dazzle produced by looking at a nuclear explosion without any protection other than that given by an exposure which was timed to last 1/10th second from the start of detonation.

Degree of Retinal Damage

As already pointed out, if atmospheric attenuation is neglected then retinal burns and dazzle, which are both dependent upon the optical system of the eye, are affected by distance only in that the area of retina involved becomes smaller as distance from the explosion centre increases. Only when the resolving power of the retinal mosaic is reached does the apparent brightness of the source decrease with increasing distance. It is then physiologically a point source.

There is ample evidence that retinal burns can be produced by nuclear explosions just as similar burns can be produced when the sun is observed for too long as, for example, during a solar eclipse. In the later stages of healing, a severe burn may be associated with such complications as retinal detachment, but its immediate tactical importance is that the subject will have a permanent blind spot equal in size to the burnt area. If the burn is other than in the line of sight, it may, depending upon its size, cause only slight impairment of ability to complete a task. Even in the line of sight however it may still be possible to read instruments if the area involved is less than 2°.

Since there are categories of slight retinal damage which can also be classed as severe dazzle, the operational problems posed by retinal burns and by dazzle must be regarded as one, the problems associated with retinal burns being merely an extreme form of those associated with dazzle.

If a severe retinal stimulus should be received, the chances of successful completion of a mission and of return to base may well depend upon training, for as the stimulus severity increases so the results of that stimulus cause more stress. Consequently a visual task which may be completed satisfactorily in a laboratory, may, in the field, become too difficult as the visual stress summates with the other stresses of the task. Training not to look at the detonation after a blink; shutters to improve upon the blink reaction time should an explosion take place near or in very clear air; if necessary, transparencies to enable the wearer to see instruments by the reflected light from clouds and yet not be dazzled: these are some of the protective measures, but training is by far the most important because under certain conditions protective devices may fail. The dazzle from clouds calls for similar measures, but the effects will be small compared with the effects produced by the image of the fireball on the retina. Whilst this light from clouds in a night explosion constitutes a major problem to the maintenance of near maximal dark adaptation, this is more of a problem for ground troops than for aircrew whose present duties do not require of them such a high degree of dark adaptation. It is to this question of degree of night vision required that one must attribute the main differences in opinions which have been expressed with regard to the severity of this problem.

Luminance

Since the brightness of the fireball varies with the temperature of the two pulses, one refers to integrated luminance, which is usually considered as being from 10^{-4} seconds (when the fireball is still subtending a very small angle at the eye) to 100 milliseconds (which is about the fastest possible blink reaction time). Fig. 1 shows the luminance calculated on the basis of the temperature for a fireball from a 20KT explosion. From this one can calculate and measure the integrated luminance for explosions of different yields by scaling the time axis by $W^{\frac{1}{2}}$ (where W = yield in kilotons). Thus for a 10 KT explosion the time scaling factor which has to be applied to Fig. 1

$$= \frac{10^{\frac{1}{2}}}{20^{\frac{1}{2}}} = 0.707$$

Since the luminance/time curve is on a logarithmic scale, this scaling merely results in displacing the curve to one side or the other. The integrated luminance for different yields is shown in Fig. 2. This was calculated as shown above, and refers to the integrated brightness within the period of 10^{-4} to 10^{-1} seconds.

Blink Reaction Times

The reason for considering integrated luminance up to 100 milliseconds is that this is approximately the duration of the fastest blink reaction time. Studies carried out by Cobb and Sears (Ref. 1) show that about 40 milliseconds after a light has been switched on, there can be detected in the electromyogram, the activity which accompanies the initiation of lid closure. This closure however does not occlude the pupil completely until 100-200 milliseconds after the flash.

Irving (Ref. 4) has found the reaction time to complete occlusion of the pupil by the lid is of the order of 100-150 milliseconds. He has found that the shorter times are associated with stimuli nearer to the fovea as well as with higher intensity stimuli. Thus the reaction time is dependent to some extent on the intensity of the perceived stimulus. As indicated by Cobb and Sears however, the stimulus need not be one of light, for any stimulus can give rise to a blink response. They suggest that the nervous pathway may be cortical and indeed one finds that the blink reflex is amenable to training. Thus a subject can either be trained not to blink when a flash appears or he can be trained to blink and to keep his eyes closed. Training in this connection consisted of verbal instruction and experience. The blink reflex associated with corneal stimulation is however unaffected by training and probably involves lower pathways mediated through the long ciliary nerves from which the cornea receives its nerve supply.

Dazzle

Fig.3, which illustrates the results of experiments, shows the recovery times after flashes by various amounts of light, all of which were delivered to the eye within 2 seconds (Ref. 7). It is possible to verify the shape of this curve by comparing the results obtained by different workers. Although recovery times measured are not necessarily to the same threshold and although different workers employed different criteria such as absolute threshold, form or legibility, these differences introduce a factor which can be considered as constant for each experiment.

The curve marked BHC was obtained by Crawford (Ref. 2), employing flashes of different durations on the fovea, and shows recovery times to 0.14 ft/L. Although his test object was similar to that employed in experiments CS and CI he shows longer recovery times. The data marked U.S. were obtained by Metcalf and Horn (Ref. 5) by looking at the carbons of a searchlight. Their recovery times refer to a threshold of 0.07 ft/L. The curve marked CS was obtained with a tungsten source, whilst point CI was obtained by observing a nuclear explosion (Ref. 9). It can be seen that the curves for each of these reports lie parallel to the curve obtained with the data of the sun experiments (Ref. 7 FPRC.787). It seems reasonable, therefore, to accept the form of this curve as representative of changes in recovery time.

In dealing with the problems of detecting a small square of light of luminance 0.14 ft/L against a black background, it is preferable to use the curve CS-CI for which this task was the specific endpoint. A task involving legibility of lettering will be more difficult and therefore will require slightly longer recovery time, whilst the task involving form perception (if the form subtends a large area) will require a shorter recovery time.

Thus from Figs. 2 and 3 it can be seen that without atmospheric attenuation a 10 KT bomb will in the first 100 milliseconds produce so much dazzle that it will take some 200-300 seconds to see against a black background a source of luminance of 0.14 ft/L, providing the flash has fallen on the fovea. If the explosion is greater than 20 KT, temporary retinal damage will begin to take place.

When considering atmospheric attenuation one would expect less damage in the form of either dazzle or retinal burns to be sustained when witnessing a detonation in the megaton range, for if one were sufficiently far from the detonation not to be seriously endangered by skin burns or by blast, the intervening atmosphere would probably attenuate the luminance to a safe level provided the exposure lasted only 100 milliseconds. To obtain a more accurate assessment of dazzle however, atmospheric attenuation must be taken into account. For this purpose Table 1 below gives the attenuation coefficient of air as a function of horizontal visibility range.

TABLE 1

Visibility (Km)	Attenuation Coefficient (σ)
2	1.2
4	0.98
8	0.5
15	0.268
30	0.132
60	0.066

Consider for example a bomb of 500 KT whose detonation is observed for 100 milliseconds from a distance of 20 Km. when the visibility is 25 Km. (daylight conditions and therefore a pupil diameter of about 4 mm. maximum). What will the luminance be when integrated over the 100 milliseconds period, and how long will it take the observer to recover so that he may see a small square of luminance 0.14 ft/L in darkness and with a natural pupil?

The atmospheric transmission in the visible range = $e^{-\sigma d}$ From Table 1

$\sigma = 0.16$ for 25 Km visibility. $d = 20$ Km, so the

$$\text{transmission} \quad \frac{1}{e^{.16 \times 20}} = 0.041$$

From Fig.2, a 500 KT explosion gives in the first 100 milliseconds, an integrated luminance of 220,000 c/cm^2/sec. With atmospheric attenuation this becomes 220,000 x 0.041 = 9,000 c/cm^2/sec.

From Fig. 3 this amount of light is associated with a recovery time of 100 secs. before a test object of luminance 0.14 ft/L becomes visible through the after image.

Pupil Size

The extent of pupillary dilatation in darkness is often over estimated. There is furthermore, continuous movement of the pupil not only in response to light and shade, but in response to emotional changes, and in general, in response to variations in balance between the ortho and para-sympathetic nervous systems. Variations in accommodation as one looks from near to far also affect pupil size. One can, however, make a reasonable approximation and say that by night conditions the pupil is twice as wide as it is by day conditions (8 mm. and 4 mm. respectively). Thus in Fig. 3, which was for flashes delivered to a daytime pupil, the total stimulating light would have to be multiplied by a factor of 4 if one considers a flash taking place at night, when the subject is also in darkness.

Thus, for example, the 9,000 c/cm^2/sec. calculated above would now be regarded as 36,000 c/cm^2/sec. and the recovery times would therefore according to Fig. 3, become about 300 seconds instead of 100 seconds for the daylight case.

The problem however is not so great, because, if one considers the retinal directional effect of Stiles and Crawford it will be found when the diameter is increased from 4 mm to 8 mm, the effective area of the pupil is not increased from 12 mm^2 to 48 mm^2 but only from 10 mm^2 to 24 mm^2 - an increase of 1.5 times instead of 4.

Probability of Sustaining a Flash on the Fovea

In considering the effect of a very bright extended source whose centre is at various distances from the fovea, it is found that as soon as the edge of the image begins to fall outside the fovea, the recovery times will rapidly decrease to values which are dependent on the amount of intraocular scatter, of atmospheric scatter, or of diffuse reflection from neighbouring reflectors such as clouds.

From one aspect, this is an oversimplification of the problem and recovery times may not in fact decrease as rapidly as the flash goes "off centre" because the scatter and diffuse reflection will be proportional to the luminance of the source. From another aspect however, recovery times may decrease more rapidly than has been suggested, because although foveal vision has here been considered as a point, it is in practice accepted as comprising an area which subtends 3°. Consequently if part of the fovea is left unstimulated, it is still possible to read with little difficulty.

Since there are such differences in the effect on foveal vision produced by a flash taking place directly in the line of sight, compared with one taking place on the periphery, and since the fovea subtends such a small portion of the whole visual field, it is clearly of importance to determine the probability (P) of a flash taking place directly in the line of sight.

Consider a flash occurring in random positions in search fields of different sizes. Different diameters of flash source will be considered, also a fovea in which maximal dazzle takes place only when some part of the image of a circular fireball overlaps on to the central 1°. It is believed that accepting a 1° field instead of an overlap on to the centre of the fovea, as has been found experimentally permissible, will weight the P values so as to compensate for the failure to consider scatter of light.

If the flash source is represented as a point in random positions, the probability of it falling in the 1° foveal field will be in the percentage which the area of the foveal field bears to that of the search field. As the flash is an extended source this fact can be taken into account by increasing the size of the foveal field to $(1 + d)^\circ$ where d is the angular diameter of the extended source. When the size of search field is 4π steradians the flash may come from any direction; (the unrestricted binocular field has been estimated to be 1.5π steradians). The results of these calculations are seen in Fig. 4. It is evident, even when considering a small search field subtending a plane angle of 40°, in which the observer knows the explosion will occur, that the likelihood of the flash taking place in direct line of sight is very small, even considering a source which is very large or very near.

This purely mathematical assessment of the risk has been purposely weighted on the side of safety, and in fact the probability of being dazzled by a fireball is less than that which has been suggested, because the maximal effects of dazzle will be sustained if the edge of the fireball comes onto the centre of the fovea and not as has been assumed in this case on the central one degree area.

Eye Movement

In this assessment of the risk no account has yet been taken of eye movements, some of which are so rapid that the image of the distant fireball will be on the retina for only a very short time. According to Westheimer (Ref. 6) some saccadic movements of the eye are as fast as $500\text{-}550^\circ$/second. An indication of the effect of such fast movements upon the retinal exposure time to a small source may be obtained by considering a source of 3° angular size and an eye movement of 600°/second. This source will travel its own diameter on the retina in 5 milliseconds and each retinal element in its track would therefore be maximally stimulated for only 5 milliseconds. From experimental work it is known that this exposure would not result in serious dazzle.

In addition to these saccadic movements there are slower movements which are normally present during fixation. When the eye is attempting to fixate in darkness, Ditchburn and Ginsborg (Ref. 3) assess that these involuntary movements are increased by four times in amplitude. This would mean that even during attempted fixation in a dark sky, involuntary eye movements of $\frac{1}{2}^\circ - 1^\circ$ would be taking place. It is probable that the same amount of involuntary movement would take place when fixation is attempted whilst looking at a bright and empty visual field such as a cloudless sky.

Protective Measures

Training. Two methods of protection are training, and a mechanical shutter. If the mechanical shutter should fail, then recourse will have to be made to training. If a transparent shutter is employed the wearer will again require to be trained. He will have to be instructed not to look at the fireball even through the transparency, because if the fireball lasts for a sufficiently long time he may sustain a burn of the retina just as a retinal burn may be sustained when observing a solar eclipse for too long through a filter which is not sufficiently dense. In this connection the yield of the weapon must be taken into account, since the duration of the explosion depends on the yield. Only with an opaque

shutter will it be possible to eliminate training and then only if the shutter is entirely dependable. It seems unlikely that such a device will be produced because a sensing element operating on flux emitted or on rate of rise of radiation may fail to be triggered by a source which is too far away. That source however may still give rise to a retinal burn if it is looked at.

Training therefore is the first essential in protection from the ocular hazard associated with a nuclear explosion. The training should consist of instruction on the advantage of looking away from a high intensity light source should one appear without warning; on the very low probability of a flash falling directly on the fovea; on the protection afforded by the blink reaction time of between 0.1 and 0.2 seconds, provided the subject does not reopen the eyes and look at the source; it should be pointed out too that the most likely danger is not from a burn of the retina but from dazzle produced by the light scattered by clouds and the atmosphere. This dazzle whilst lasting a long time if one requires to re-adapt to low thresholds need interfere with visibility of instruments only for a few seconds if these have been illuminated by white flood-lighting to a luminance of instrument marking of about 5 foot lamberts or above (Reference 7).

The use of a simulator to give an impression of the angle subtended by a fireball of different yields and at different distances might with advantage be combined with a high intensity light source which could provide a source of calculated dazzle. The effect upon aircrew performance might be demonstrated by giving a flash on the fovea whilst the subject is "flying" an aircraft simulator under simulated night conditions.

Shutter

Whilst more protection may be derived from an opaque shutter, if this device remains over the eyes for the duration of the explosion the pilot who is subject to the effects of a weapon in the megaton range may be blinded for half a minute - not by the dazzle but by the protective shutter over his eyes. It seems therefore that one must have a transparent shutter which at least would enable the wearer to see his instruments should the cabin be illuminated by intense light from the explosion. The transparent shutter would therefore protect principally from dazzle by reflected light, but as already indicated, the subject would still have to be trained not to look directly at the fireball, otherwise his dazzle will be more severe and he may in addition sustain a retinal burn. The filter suggested for such a device is one of neutral density and of 10% -15% transmission which would allow it to be employed also as a sun visor.

Since the eye can look at the fireball directly for as long as 100 milliseconds depending on distance, attenuation, and yield, a shutter need not close in a very short time, and this simplifies the mechanism involved. Thus the difficulties associated with opaque shutters and instrument visibility, could now be solved by a shutter over the canopy. A roller blind type of shutter might be the simplest protective device if it were combined with white flood lighting of instruments.

To the list of protective devices given in Reference 8 should be added the electro-mechanical shutter which has been developed by the United States Air Force. This device consists of two superimposed graticules which when moved by a very small amount render the whole field opaque. The movement is produced by detonation of a small cartridge

which in turn is triggered by a light sensing element. This device has been reported to operate in less than a millisecond. The other device which should be mentioned is a photochromic substance being developed by the National Cash Register Co., in U.S.A. They have produced a substance which, dissolved in various media, changes under the action of light from transparent to dense in a few milliseconds. The process is reversible and when the light is removed the substances becomes transparent again either with equal speed or in several hours depending upon the medium in which it is dissolved. It is claimed that it may be possible to achieve a filter of density 3 by this means, but at present the problems faced are the method of applying this device to goggles in the form of gelatin or to a visor in the form of a fluid sandwich. The sensing element employed with such shutters is usually activated by the intensity of light falling on it. A large distant explosion may therefore fail to a trigger a sensing element which would be triggered by a small explosion at close range or by a large distant explosion in very clear air.

The time in which the shutter has to close must be dictated by such factors as size of the explosion and distance beyond which protection is required, these factors themselves being dictated by the limits beyond which the subject may be expected to survive the effect of blast and thermal radiation.

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(9) Whiteside T.C.D. (1959) "The observation and luminance of a nuclear explosion". Air Ministry Flying Personnel Research Committee Report FPRC 1075.

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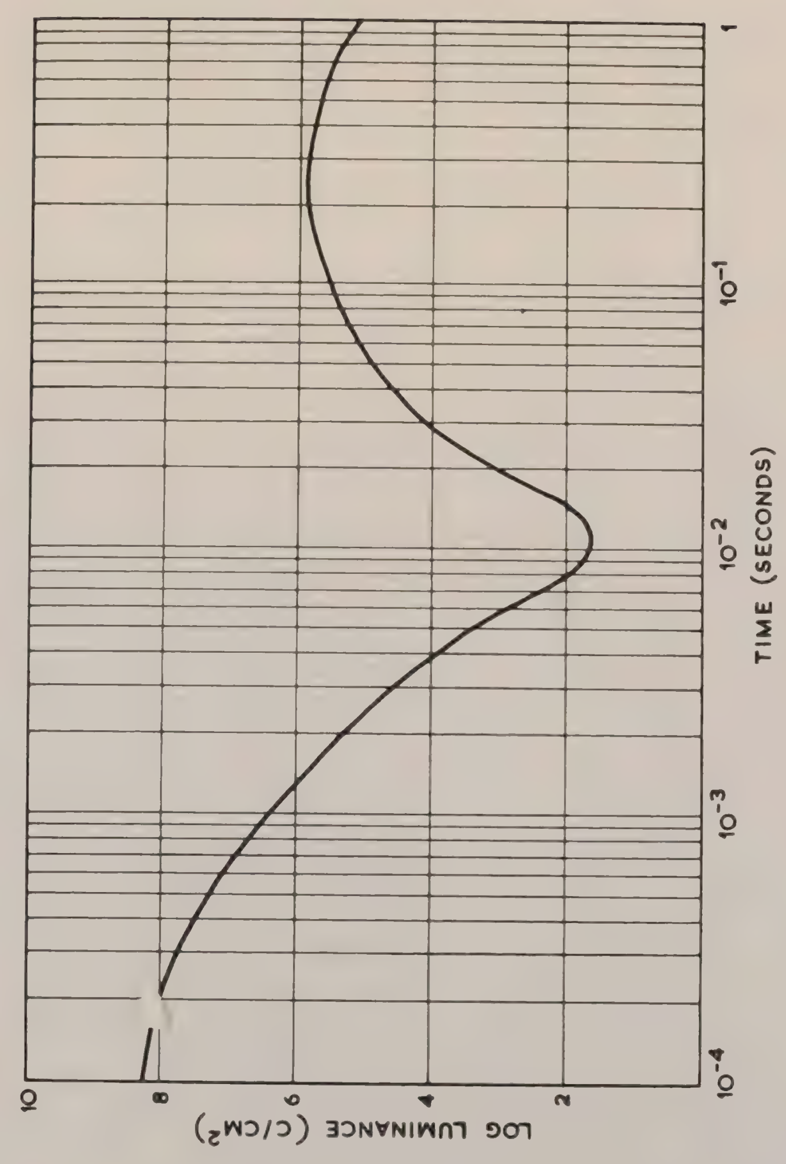
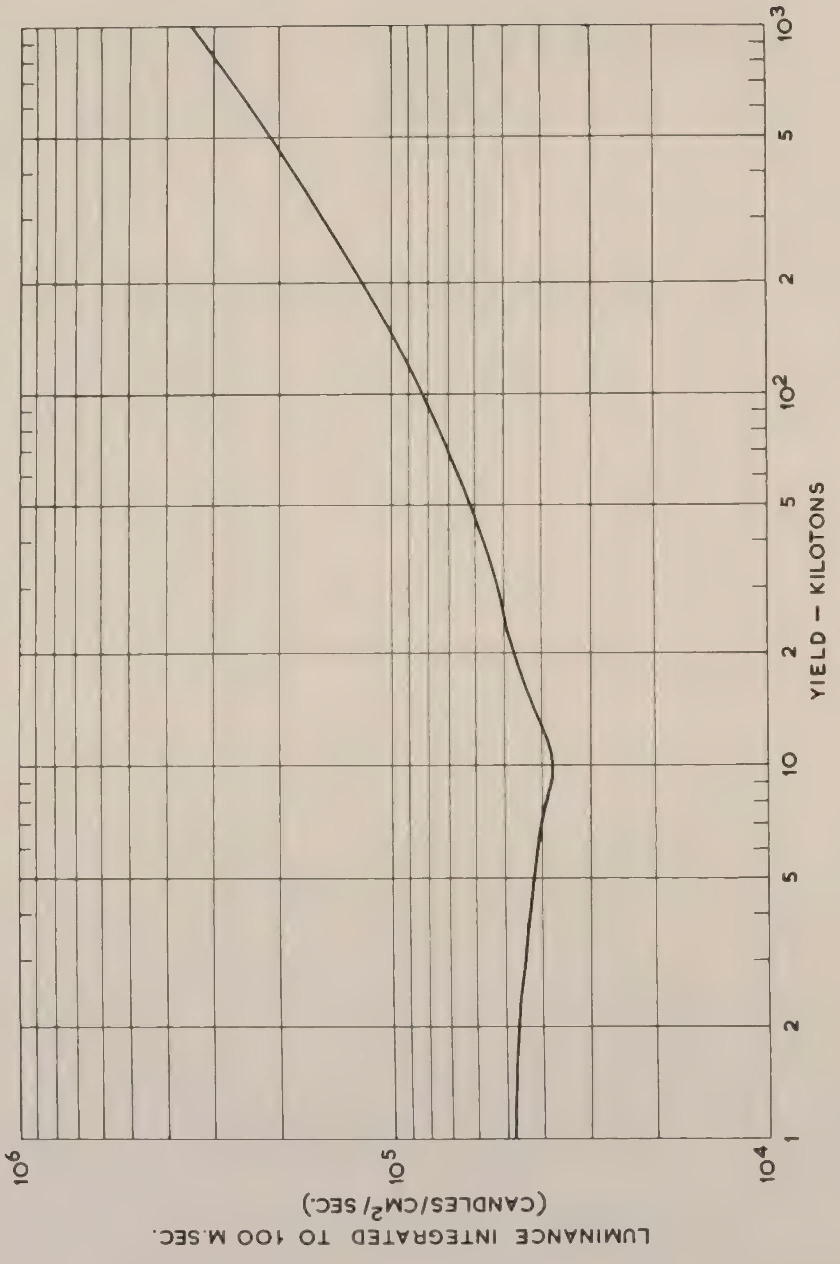


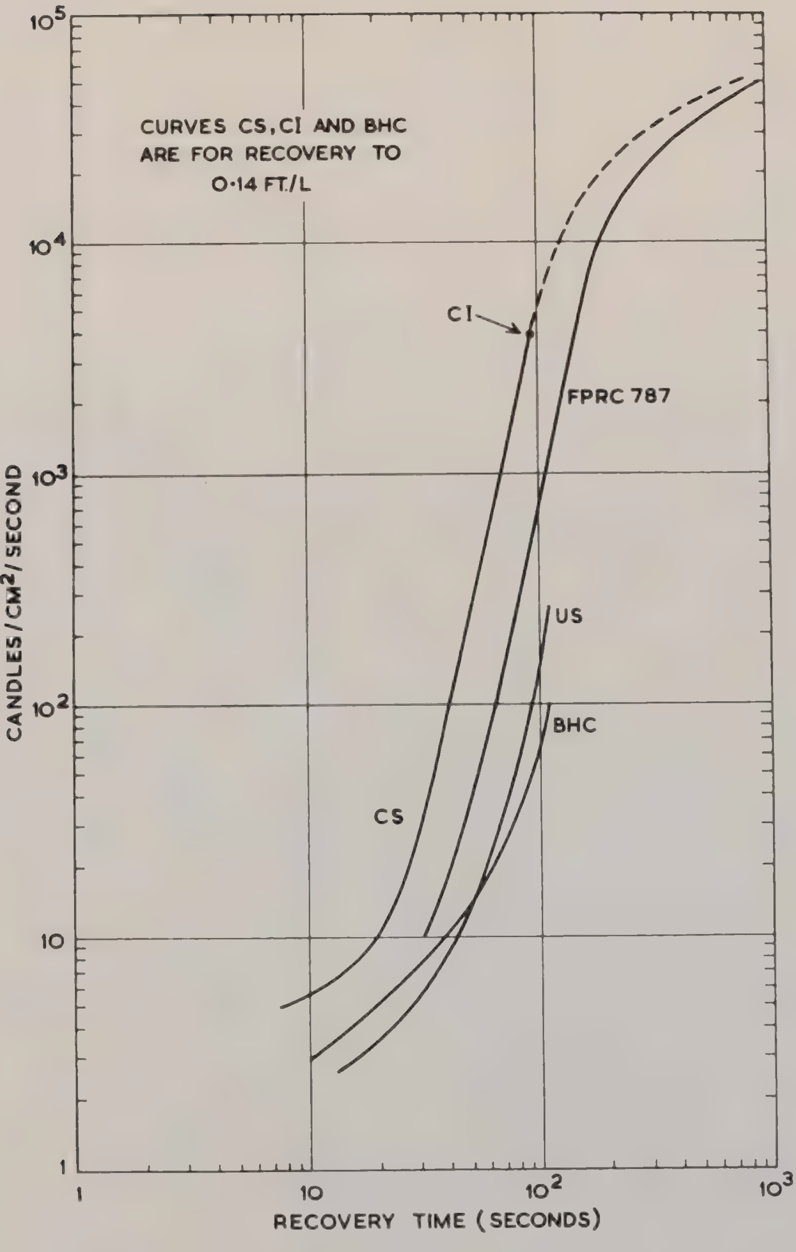
LUMINANCE OF FIREBALL
DERIVED FROM TEMPERATURE

CONFIDENTIAL

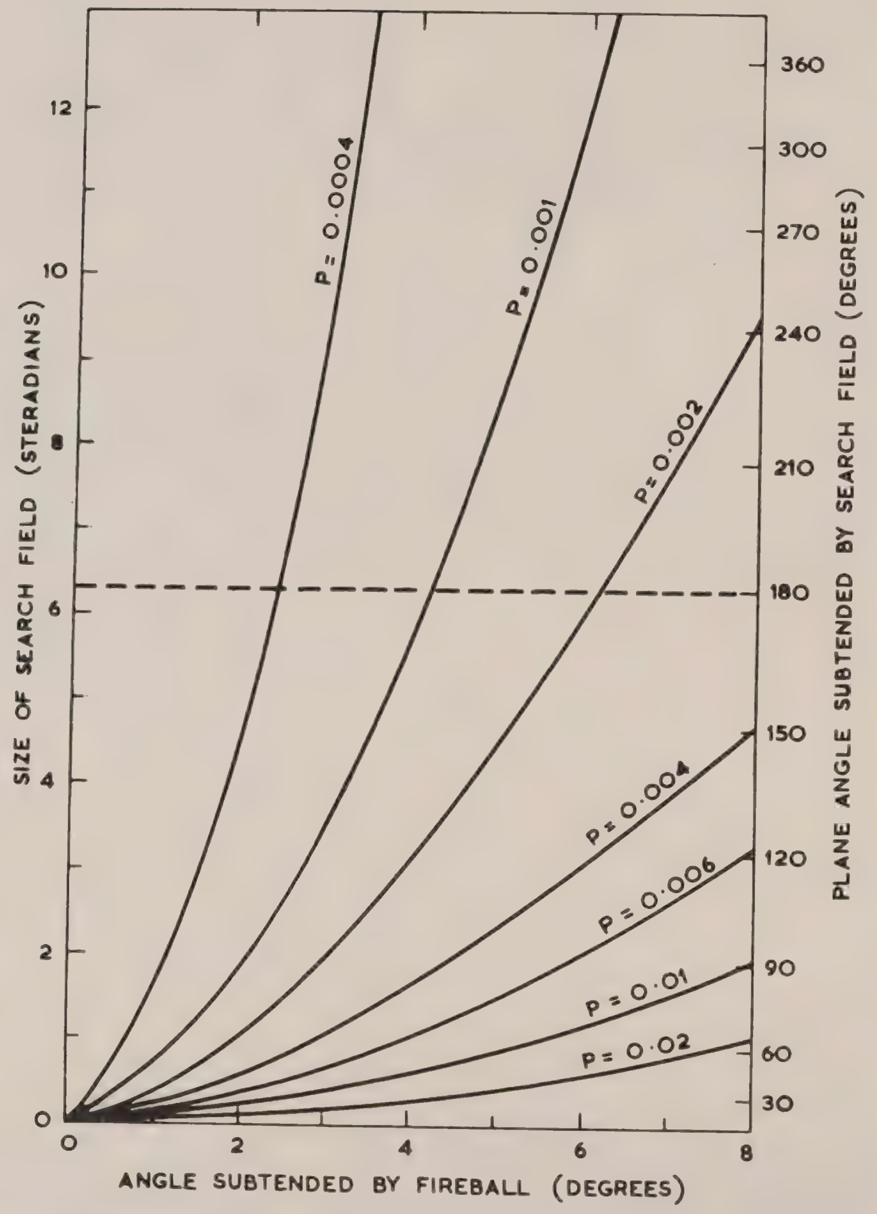


VARIATION OF INTEGRATED LUMINANCE WITH YIELD
(NO ATMOSPHERIC ATTENUATION)

CONFIDENTIAL



COMPARISON OF RECOVERY TIMES



PROBABILITY OF AN IMAGE OF A FIREBALL FALLING WITHIN THE CENTRAL 1° OF THE FOVEA CENTRALIS

CHAPTER 8 - THE PROTECTION AFFORDED BY CLOTHING

8.1. Introduction

Ordinary clothing, especially that worn in temperate and cold climates where the outer garments are usually made of wool, provides valuable protection against flash burns over the area it covers. The face and hands and, in the case of women and children, the legs, are unlikely to be adequately covered, but this can be corrected by the wearing of gloves and long trousers. Satisfactory protection of the face is more difficult to achieve without seriously impeding vision. Useful protection can be secured by arranging for the head and neck to be well covered and for the face to be heavily shaded by a projecting peak and partially obscured by hanging fabric. Japanese experience showed that burns through clothing were more likely to occur where the garment was drawn tightly in contact with the skin. The great value of light coloured clothing was also demonstrated, but light colours conflict with the camouflage requirements of the Services.

A great many factors enter into the protective qualities of a clothing assembly against thermal radiation, amongst which may be mentioned:-

(i) the number of layers;

(ii) the reflectance of the outer and subsequent layers;

(iii) the transmittance of the layers;

(iv) the space between the layers and between the innermost layer and the skin;

(v) the thermal capacity of each layer;

(vi) the 'flashing' temperature of the outer layer.

Other factors are undoubtedly involved, and the behaviour of multi-layer assemblies is particularly complicated. Moreover, the properties of the fabric change during exposure to the radiation. It has not proved possible to relate burn protection to fabric properties in any simple way. In the following Sections of this Chapter some account is given of laboratory investigations of thermal effects on clothing, and also of full-scale trials results.

8.2. Laboratory Studies with Animals

The protection afforded by clothing against high intensity radiation pulses has been the subject of laboratory studies over a number of years at the University of Rochester, New York, under contract with the U.S. Atomic Energy Commission. The source of radiation used in this work is a carbon arc which, in conjunction with a 24 inch ellipsoidal mirror, provides intensities up to approximately 34 cals/cm^2/sec. The shutter, as normally operated, gives a trapezoidal pulse, but a pulse shape resembling that from an atomic explosion can also be reproduced.

The workers at Rochester do not consider that any instrumentation methods so far developed can be reliably used to preduct the probability of a second degree burn. They accordingly employ small white pigs of about 20 lbs. weight, the skin of these pigs being structurally similar to that of man and responding similarly to thermal stimuli. Thus, for 0.3 sec. exposures, the average level of thermal energy required to produce a second degree burn on the human skin was 4.0 cals/cm^2. See also Chapter 7, Section 7.3.2. - Flashburns. It has also been shown that the burns produced on pigs by the Rochester equipment are similar in their characteristics and healing properties to those observed when the animals are exposed to the thermal radiation from an atomic weapon.

Nevertheless, in drawing conclusions from the Rochester data, it should be kept in mind that the latter are concerned with the probability of producing second degree burns on anaesthetised animals when small areas (1.7 cm. diameter) are exposed to trapezoidal thermal pulses. The results do not necessarily apply directly to human skin, to larger burn areas, to other degrees of burn, or to different pulse shapes.

It has been shown that the protection afforded by fabrics, particularly multi-layer assemblies, varies in a complicated way with irradiance and exposure time. A specified thermal dose applied at different exposure times will produce effects which will depend on whether the outer layer bursts into flame, acts as a thermal reservoir supplying heat to the skin after completion of the exposure, is destroyed with the dissipation of energy, or is destroyed before the end of the exposure so that the radiation impinges on the next layer. Studies at fixed exposure times are therefore of limited value, and data must be obtained over a range of exposures and intensities.

The value of an air space between the fabric and the skin is very marked. For an exposure time of 0.5 seconds, the protective index (defined as the ratio of the approximate dose required for a 50% probability of producing a second degree burn under the fabric, to the corresponding value for bare skin) for a 9 oz. olive-green cotton sateen fabric, rose from 1.5 when the cloth was in contact with the skin to 3.0 when it was separated by a 2 mm air gap. When a two-layer assembly of sateen over knitted underwear fabric was separated from the skin by a 5 mm air gap, the protective index showed a 4-fold increase (References (1) and (2)).

The effect of applying flame-proofing treatment to cotton sateen fabrics was also examined at Rochester, U.S.A. Such proofings usually involve the impregnation of the cloth with some 15-20% of flame-proofing chemicals; thus, the thermal properties of the cloth are affected and the burn protection on the flame-proofed cloth in direct contact with the skin may be slightly inferior to that of the corresponding unproofed cloth. The mechanism of action of some flame-proofing treatments is to modify the thermal degradation of cellulose so as to favour the production of tars rather than inflammable gases. When a flame-proofed cotton fabric is

/exposed

exposed to high intensity radiation, these hot tars may, in some circumstances, distil onto the skin and cause serious burns. Flame-proofing treatments are however, valuable for application to the outer layer of two-layer cotton assemblies such as might constitute a tropical kit. If the outer layer is not flame-proofed it ignites with sustained burning, which itself causes burns. It should be noted that this flaming does not occur when the fabrics are in skin contact. This effect is shown in the following results:-

Material	Protective Index	
	Contact	Separated 5 mm from skin
5 oz. Green Cotton Oxford Cloth over knitted undergarment fabric	5.5	8.5
5 oz. Green Cotton Oxford Cloth with outer flame-proofed fabric	4.0	11.1

The protective values of clothing assemblies given by Rochester are substantially lower than those reported by the U.S. Naval Materials Laboratory, where the critical energy required to produce a burn was assessed by a heat-sensitive backing paper. On the basis of Rochester's figures, which may be conservative, the following estimates are given for the probable performance of military clothing:-

No. of Layers	Type of Uniform	Energy required to produce a casualty $cals/cm^2$
2	Tropical, light weight	7
4	Temperate	40
6	Cold weather, heavy wool	100

The temperate and cold weather uniforms therefore give a high measure of protection, which could be further increased by wearing additional layers. The main problem is to improve face and hand protection to a similar degree. Tropical clothing presents considerable difficulty, but re-design to give a looser fit, and the application of a permanent flame-proofing to the outer layer, might lead to some improvement.

Further information on the thermal effects on textiles and clothing is given in Section 4.2.1. of Chapter 4.

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(1) U.S. University of Rochester, Report No. U.R.354 (P.50377) "Protective Qualities of Fabric Expressed by a Protective Index".

(2) U.S. University of Rochester Report No. U.R.355 (P.50376) "Influence of Exposure Time and Irradiance on the Thermal Protective Qualities of Two-Fabric Assemblies".

8.3. Full-scale Tests of Thermal Damage to Military Uniforms

The effect of thermal radiation from a weapon of about 15 KT yield, upon full-scale Service clothing assemblies exposed on tailors' dummies, was studied at Operation Buffalo (Reference (1)). The object of the tests was to compare the effects on clothed men with the effects predicted from observations made on small fabric specimens. The results obtained are summarised in Table I.

TABLE I - Effect of Thermal Radiation (Approx. 15 KT Weapon) on Surface Layer of Uniforms and Fabric Sample Assemblies

Thermal Dose $Cals/cm^2$	Battledress		Combat Suit		Tropical Suit KD/	
	Full Scale	Sample	Full Scale	Sample	Full Scale	Sample
1.3	-	0	-	0	-	0
2.0	-	0	-	0	-	0
2.6	-	0	-	0	-	0
3.8	-	0	-	0	-	0
5.0	-	2	-	0	-	0
7.2	-	3	-	3	-	2
9.0	2	3	2	4	5*	4
12.5	2	3	3	4	5*	-
16.5	2	4	4	5	5*	-
24.5	4	4	5	5	5*	-
33.0	4	-	5	-	5*	-
51.0	5	-	5	-	5*	-
65.0	-	-	-	-	-	5
85.0	-	-	-	-	-	-
115.0	-	-	-	-	-	5

Code:- 0 = no apparent damage

1 = just perceptible scorching

2 = slight scorching

3 = moderate charring

5 = complete destruction

* = complete destruction of whole assembly and dummy

/ = the tropical suit KD consisted of drill trouser and cellular jacket, whereas the only fabric sample used for comparison was drill.

Conclusions

The following conclusions are made in Reference (1).

(i) The current serge battledress and sateen combat suit, give excellent protection against thermal radiation, except that both types naturally fail to cover all bare skin.

(ii) The R.A.F. Service dress also gives excellent protection, but it is considered that the dark blue colour may slightly reduce its protection compared with khaki battledress.

(iii) The tropical uniform offers very little protection and may in fact increase the effect of thermal radiation by ignition.

(iv) The R.A.A.F. flying suit is similar to tropical uniform in that it easily ignites and is therefore unsatisfactory with respect to thermal protection.

(v) The oversuit tank crew is unsatisfactory because of the low melting point of the plastic outer layer.

(vi) It is considered that the use of small fabric samples to test the effects of thermal radiation on uniforms is reasonably satisfactory.

Reference should also be made to Section 4.2.1 of Chapter 4, which gives an account of thermal effects on textiles, including Service uniform fabrics.

References

(1) A.W.R.E. Report T11/58. Operation Buffalo Target Response Tests, Materials Group, Part 6. "The Effect of Thermal Radiation from a Nuclear Explosion on Service Uniforms. (Confidential)

8.4. Critical Radiant Exposures for Burns under Clothing

The complexity of the interrelations among the factors which control the protective value of clothing assemblies (see Section 8.1) makes an accurate prediction extremely difficult. Table 1 lists estimates of radiant exposures required to effect burns under clothing and is based on information obtained from References (1) and (2). These values are considered representative of average field conditions, but it should be remembered that they are dependent upon many variables which are not easily defined, and are probably correct within a factor of 2. Additionally, in extremely cold or wet weather, the thermal intensities required for burns are considerably increased.

Table 1

Critical Radiant Exposures for Burns under Clothing
(expressed in cal/cm^2 on outer surface of cloth).

Clothing	Burn	1 KT	100 KT	10 MT
Summer Uniform	1°	8	11	14
(2 layers)	2°	20	25	35
	3°	25	33	44
Winter Uniform	1°	60	80	100
(4 layers)	2°	70	90	120

References

(1) Capabilities of Atomic Weapons (1957) U.S. Dept. of the Army TM 23-200. p. 6-4 (Confidential)

(2) Staff Officers' Field Manual - Atomic Weapons Employment. U.S. Dept. of the Army, FM 101-31 (1956) p.72. (Secret Atomic)

PART VII - DAMAGE BY NUCLEAR RADIATION

CONTENTS

Chapter 9. Radiac Instrumentation

9.1. Types of Radiation

9.2. Measurement of Personal Doses (Flash Dosimeters)

9.3. Measurement of Contamination of Areas (Survey Meters)

9.4. Measurement of Contamination on Personnel, Food and Water (Contamination Meters)

9.5. Measurement of Radioactivity for Special Purposes

9.6. Service Requirements

9.6.1. Storage and durability
9.6.2. Calibration
9.6.3. Response time

9.7. Details of Current Radiac Instruments.

CHAPTER I - INTRODUCTION

At the instant of detonation of any atomic or thermonuclear weapon gamma rays and neutrons are emitted at high intensity for a brief period of the order of a microsecond. This radiation is followed by emission of alpha particles, beta particles, gamma radiation and neutrons from the fission products and bomb residues in the cloud. As the cloud rises and cools and is later dispersed by the wind these fission products and residues condense and, with any surface material which may have been sucked up into the cloud, ultimately return to the surface as fallout. The radiation from fallout consists mainly of alpha, beta and gamma activity. The two cases are distinguished by the terms 'initial' and 'residual' nuclear radiation, but as the fission products are extremely active immediately after formation, some authorities prefer to consider nuclear radiation from the cloud as part of the initial radiation for a period which then requires definition. One minute is commonly taken as the demarcation point, being a time in which a high proportion of the initial radiation will have been emitted. Half the initial gamma radiation appears within 0.5 of a second in the case of a 20-KT bomb, and within 5 seconds in the case of a 5-MT bomb.

It appears unlikely that nuclear radiations will be of sufficient intensity outside the radius of total annihilation to affect appreciably the chemical or mechanical properties of materials, except in certain special cases such as photographic and perhaps electronic equipment which are covered in Part VIII. The principal importance of these radiations is therefore on account of their biological effects, especially on man.

The most important initial nuclear radiations are high energy gamma rays (1-10 Mev) and neutrons. The hazard from fallout depends to some extent on whether it is external i.e. from material lying on the ground, or internal, from material taken into the body via the lungs, mouth or open wounds. In the external case gamma activity is the principal hazard. The beta activity is of relatively short range in materials so that its effects are limited to surface tissues, and the alpha particles are absorbed even in a few inches of air. The case is very different for internal deposition, as certain chemical are strongly held in the body in places where their short range but heavily ionising radiations can do considerable damage.

The accounts of each type of radiation from a weapon of a given size under various conditions of burst are given in Reference (1), Chapters 5 and 6. This reference also discusses the energy spectra of the radiations and their angles of arrival at a target at a given distance. For ease of reference certain of this information is summarised in this part of the manual, but Reference (1) should be consulted for fuller details. An unclassified account is given in Reference (2). The importance of neutron gammas is discussed in Reference (3).

In particular it must be emphasized that there is no precise general relationship between the blast and thermal yields of weapons and their output of initial nuclear radiations. It depends on the design of the particular weapon. Data for neutron output are particularly sensitive in this respect and the figures normally quoted for neutrons should be regarded as lower estimates which may be exceeded by factors of 10-30 in special cases.

Chapters 2 and 3 of Part VII discuss quantitatively the various biological effects on man and give the maximum dose permissible in various circumstances. Chapters 5 and 6 cover the extent to which radiation from a given source may be reduced by shields of various materials. Chapter 7 discusses the nature and movements of fallout material, the removal of which is considered in Chapter 8. Part VII concludes with a brief review of standard Radiac instruments for the routine monitoring of various types of activity.

References

(1) A.W.R.E. Manual on The Effects of Atomic Weapons, 1955. (Secret/Atomic/U.K.Eyes Only)

(2) The Effects of Nuclear Weapons. U.S.Atomic Energy Commission, 1957.

(3) On the Origin of the Initial Gamma Radiation. Stewart K. 1957 Tripartite Conference Paper AWEC/P(57)213. (Secret/Atomic)

CHAPTER 2 - BIOLOGICAL EFFECTS OF NUCLEAR RADIATION

2.1. The Nature of Biological Effects on Man

As explained in the introduction to Part VII, the nuclear radiation effects of an atomic explosion may be divided into two categories, namely, the initial radiation (gamma rays and neutrons) and the residual radiations (gamma rays, alpha and beta particles). Although different radiations may cause ionisation by different mechanisms and to varying degrees, the ultimate biological response of cells composing living tissue exposed to these radiations is to suffer cellular damage or destruction.

The effects of nuclear radiations on man depend however, not only on the total radiation absorbed, but on the rate of absorption. The generally accepted explanation for this is that if the dose-rate is small the damaged tissues have a chance to recover, at least partially, but where intensive radiations are received the recovery cannot keep pace with the damage. This fact makes it necessary to distinguish between acute exposure (a single short dose of radiation) and chronic exposure (a prolonged dose). Exposure to the initial radiations from an atomic bomb, which are taken as being of one minute's duration, may therefore be regarded as acute.

The gamma (or X-) radiation dose received by an individual is described in terms of the roentgen unit (r) (see Glossary for definition). It is a measure of the strength of the radiation field at a given location, and the radiation dose in roentgens is therefore referred to as an "exposure dose". Neutron radiation dose may be estimated by the rem (roentgen-equivalent-man) unit, which is the amount of energy absorbed per gram of mammalian tissue to give the same biological effect as one roentgen of gamma or X- radiation.

Table 1, taken from Reference (1), gives an approximate indication of the early effects on human being of various acute doses of radiation, assuming exposure of the whole body. Individuals may, however, vary considerably in their reactions to nuclear radiations.

TABLE 1

Acute Effects of Whole Body Penetrating Ionizing Radiation on Human Beings

Dose in 1 week	Effect
0-150 r	No acute effects - serious long term hazard.
150-250 r	Nausea and vomiting within 24 hours, minimal incapacitation after 2 days.
250-350 r	Nausea and vomiting in under 4 hours. Some mortality will occur in 2-4 weeks. Sympton free period 48 hours-2 weeks.
350-600 r	Nausea and vomiting under 2 hours. Mortality in 2-4 weeks, or prolonged incapacitation.
600 r	Nausea and vomiting almost immediately. Mortality in 1 week.

Table 2, also from Reference (1), summarises the estimated effects of doses received over periods up to three months.

The residual radiations arising from fission products may constitute a chronic hazard, either as external or internal radiation. The former applies to instances in which the source of radiation lies outside the body and the latter refers to cases where the source is taken into the body by ingestion, inhalation, or through breaks in the skin. The effects of residual radiation from external sources are dealt with in Section 2.3, and in some respects the results of chronic doses of such radiation may be expected to be similar to those for acute doses, the severity depending on dose-rate and total accumulated dose.

The hazard caused by a radioactive substance taken into the body will depend on the solubility and chemical and physical properties of the substance, which determine how it is absorbed. The effects of such absorption may be long-delayed, but ultimately very serious; these effects are described under Section 2.4.

The ultimate injury from radiation received from mixed and intermittent sources will be a combination of the separate radiation effects to which an individual is exposed. Thus the dose from initial gamma radiation must be added to the 'rem' from neutrons and the gamma dose from residual radiations. The dose from external beta radiation is assessed separately, since it causes a surface effect rather than internal injury.

Other types of injury, when combined with sub-lethal exposure to nuclear radiation (e.g. about 150-250r) are expected to produce more severe results than in the absence of nuclear damage. Thus sub-lethal thermal burns combined with exposure to nuclear radiation are expected to produce earlier and more severe reaction than would occur in uncomplicated burns of similar degree. Reference (2) describes observations which were made of thermal burns on pigs and dogs which had also received fatal or near-fatal doses of nuclear radiation. The uninterrupted healing of severe burns in pigs dying of radiation sickness was a stricking phenomenon. If the burn progressed to the point of partial epithelialization, then healing proceeded in spite of mortal radiation sickness. But granulating biopsy wounds or burns became gangrenous and sloughed when radiation sickness appeared. This may indicate that all efforts should be made to promote healing of burns and that all definitive surgery should be done early in those who have received significant amounts of ionising radiation.

A recent review of the biological effects of ionising radiations is given in Reference (3). Reference (4) summarises much useful material, including observed biological effects of radiation, medical evaluation of personnel, treatment of injuries, and permissible doses. Extensive bibliographies are given.

It should be noted that only the immediate biological effects of nuclear radiations are dealt with in this chapter. A discussion of the genetic effects is outside the scope of this Manual, but a review of this subject will be found in Reference (3).

References

(1) Alpen, E. L. "Radiological Hazard Evaluation". 12th Tripartite Conference on Toxicological Warfare (1957) (Secret/Discreet)

(2) Report UR.254 - "Thermal Burns from the Atomic Bomb". University of Rochester, (N.Y.), Atomic Energy Project.

(3) The Hazards to Man of Nuclear and Allied Radiations - Medical Research Council (HMSO Cmd. 9780).

(4) U.S.A.F. Radiobiology Guide. Wright Air Development Center, Technical Report 57-118 (April, 1957).

TABLE 2

Estimated Medical Effects of Radiation Doses Expressed as Percentage of Working Force Affected*

Total Dose (r)	Duration of Continuous Exposure					
	1 day	3 days	1 week	1 month	3 months	Effects
0 to 75	0% sick				0% sick	None
100	2% sick	0% sick			0% sick	None
125	15% sick	2% sick	0% sick		0% sick	None
150	25% sick	10% sick	2% sick	0% sick	0% sick	None
200	50% sick	25% sick	15% sick	2% sick	0% sick	Some late effects
300	100% sick 20% dia	60% sick 5% die	40% sick	15% sick	0% sick	Some late effects
450	100% sick 50% die	100% sick 25% die	90% sick 15% die	50% sick	0- 5% sick	Some late effects
650	100% sick 95% die	100% sick 90% die	100% sick 40% die	80% sick 10% die	5-10% sick	Some late effects

*This table applies to healthy, young adults under usual working conditions.
The percentage of fatalities will be decreased with adequate medical treatment.
The percentage figures are based on an interpretation of the best current available evidence and may be changed as more information is accumulated.

2.2 Effects on Man of Initial Radiations

We are concerned in this section with gamma rays and neutrons produced during the first minute following a nuclear explosion. This time is short compared with the biological response times, so that the biological effect for a given total dose of initial radiation is approximately independent of dose-rate. In the case of a surface burst the dose received from secondary sources during the first 24 hours may be counted as a part of the initial dose.

The clinical results of exposure to ionising radiations may be considered under four headings:-

(a) The effects of an overwhelming dose of radiation (over 5,000 roentgens).

(b) Supra-lethal radiation injuries (over 600 roentgens)

(c) Lethal radiation injuries (300-600 roentgens)

(d) Sub-lethal radiation injuries (100-300 roentgens).

(a) Massive doses of radiation will seldom be encountered in the absence of severe heat and blast effects, but occasionally the two other effects may have been prevented by shielding. In such cases death will be comparatively early (within a few hours or days) and incapacity will be almost immediate.

(b) Most of the cases suffering supra-lethal irradiation will vomit within the first two or three hours, and continue with generalised malaise during the first day or two, with a return of gastro-intestinal symptoms by about the fourth day after exposure. Persistence of these symptoms is of bad prognostic significance and it is likely to be followed by soreness of the mouth and pharynx, with rising temperature towards the end of one week and death at latest by the tenth day after exposure. Epilation (loss of hair) is not likely to have developed in these cases, and haemorrhages will not be marked. There will be some intestinal ulceration.

(c) Lethal radiation injury will be caused by exposure in the region of 300-600 roentgens and will result in approximately 50 per cent deaths. Nausea and vomiting will occur during the first 24 hours. This will be followed by a latent period, with no definite symptoms, lasting for about a week. During this time if a blood count can be performed a fall in lymphocyte count will be detectable. The first signs of epilation may be detectable after nine or ten days, and the fall of hair will be marked after fourteen days. This effect may be absent if the hair of the scalp has been partially protected by the wearing of a steel helmet.

The main lesions of this group will be associated with haemorrhage, necrosis (cell destruction), and secondary infection. Recurrence of loss of appetite and malaise begin about the middle of the third week after exposure, and towards the end of this week there may be a rise in temperature. By this time the white cell count is usually at a low level. Approximately three weeks after exposure there is soreness of the mouth, together with anaemia, due to impairment of red cell formation and haemorrhage, which increases and becomes more marked when petechial (skin) and internal haemorrhages occur.

Infection, in the absence of anti-biotics, rapidly becomes generalised. In such cases there is little or no cellular reaction. Ulceration of the

bowel frequently occurs. Death associated with haemorrhages most commonly occurs towards the middle of the fourth week after exposure. Mortality is about 50 per cent.

Those who survive this severe illness are left in a weakened emaciated state with poor ability to overcome infection. In some of them, co-existing diseases such as tuberculosis light up and recovery takes a long time; in most cases however, recovery is never complete. Testicular damage causes temporary sterility, although in most cases recovery will eventually occur. A dose of the order of 300r to the overies will cause permanent sterilisation.

Late effects among the survivors of severe radiation injury include an increased tendency to the development of leukaemia and minor cataracts, and there is also the probability of genetic effects which will only be apparent in subsequent generations.

In the early stages of pregnancy, abortion, possibly followed by the death of the mother, may occur.

(d) In cases where a sub-lethal degree of exposure of radiation has occurred there will be some nausea and vomiting several hours after exposure. Following this there will be a latent period without any symptoms attributable to irradiation. This will be much longer than for cases of lethal exposure. In general, the greater the length of the period without symptoms the better will be the prognosis. Towards the end of the third week there may be some tendency to epilation, followed by loss of appetite and general malaise. Soreness of the mouth, anaemia, gastro-intestinal symptoms, and even haemorrhages may appear to a much less extent than among severe cases, and by the end of the fourth week most of the patients will begin to recover, although pale, anaemic and somewhat emaciated. In general, unless there are complications, recovery will be the rule.

Minor manifestations of radiation damage will also occur. In many such cases there will be no symptoms, but careful examination, particularly of the blood system, would show evidence of radiation damage. In general, such cases should not, if possible, be further exposed to radiation.

The injury effects which have just been described are summarised in Table 1, and Figure 1 (taken from Reference (1)) gives the percentage of casualties from nausea and vomiting within two hours, as a function of gamma radiation dose received. Figure 2 (from Reference (2)) gives the incidence of sickness and death due to acute exposure to various doses of nuclear radiation.

Neutron Effects

The neutrons emitted in a nuclear explosion can, like gamma rays, penetrate considerable distances in air and cause similar biological damage. More than 99 per cent of the neutrons produced by the fission of uranium or plutonium are released within a micro-second of the explosion, and these are described as prompt neutrons. The remainder of the neutrons, referred to as delayed neutrons, are produced subsequently by the decay of certain types of fission fragments. Delayed neutrons are not significant for biological consideration. Following an explosion, neutrons are also produced by the action of gamma rays on bomb materials, but the number is relatively very small and may be ignored.

Neutrons, like gamma rays, can cause radiation sickness and death, although the timing of the illness may be rather different. The neutron radiation dose may be estimated in rem (see Section 2.1) or in rads, where

1 rad is the unit of absorbed dose, equal to 100 ergs per gram of tissue. The relative contribution of neutron and gamma radiation to total biological dose is shown in Figure 3, taken from Reference (2).

Neutrons transfer energy to the tissue by a different mechanism from that of gamma rays, and produce greater biological damage. The relative biological effectiveness (RBE) is the ratio between the quantity of energy delivered to the tissue by gamma rays compared with neutrons to produce the same biological effect. For many observed biological effects neutrons appear to have an RBE 1-4 times that of gamma rays, but in some instances values as high as 15-30 have been found (Reference(1), page 184). The production of cataracts (lens damage) appears to have an RBE of 4-8, and this may be a limiting factor in determining permissible exposure to neutrons. In Reference (2), page 468, it is recommended that a value of 1.7 be taken for the RBE for casualties from bomb neutrons. This figure has been obtained from observations on mice, but some confirmation is given by analysis of data on radiation injury and death after the nuclear explosions in Japan.

Further more detailed accounts of the biological effects of initial radiations may be obtained from Reference (2), page 466, and References (3), (4), and (5).

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(1) Capabilities of Atomic Weapons, U.S. Armed Forces Special Weapons Project TM 23-200 (1955) (Confidential/Atomic)

(2) The Effects of Nuclear Weapons, U.S.A.E.C. (1957).

(3) Bugher, J. C. "Delayed Radiation Effects at Hiroshima and Nagasaki". Nucleonics, Vol. 10, No. 9, p.18 (1952).

(4) Hempelmann, L. H., Lisco, H., and Hoffmann, J. G. "The Acute Radiation Syndrome: A Study of Nine Cases and a Review of the Problem". Ann.Int.Med., Vol. 36, p.279 (1952).

(5) Oughterson, A. W., and Warren, S. (Editors) "Medical Effects of the Atomic Bomb in Japan", National Nuclear Energy Series Division VIII, Vol. 8, McGraw Hill Book Co., New York, 1956.

TABLE 1

The Clinical Symptoms of the Radiation Syndrome

Average days after exposure	Supra-Lethal Radiation Injury (over 600 r)	Lethal Radiation Injury (300-600r) 50% Deaths at 450r	Sub-Lethal Radiation Injury (100-300r)
0	Nausea and vomiting within 1-3 hours	Nausea and vomiting after 2-4 hours	Variable, depending on the individual
1	Generalised malaise	No definite symptoms	-do-
2-3	Malaise and anorexia	-do-	-do-
4	Nausea and vomiting	-do-	-do-
5	Vomiting and diarrhoea	-do-	-do-
6	Soreness of mouth and throat	-do-	-do-
7	Fever	-do-	-do-
8	Rapid emaciation	-do-	-do-
9	Death	Beginning epilation	-do-
10	Mortality probably 100%		-do-
17		Anorexia and malaise	-dop
18			Beginning of epilation
19		Fever	Anorexia and malaise
20		Gangrene or soreness of mouth	
21			Sore mouth
22			Pallor
23		Pallor	
24			Diarrhoea
25		Petachiae	Moderate emaciation
26		Mucosal haemorrhage	
27		Diarrhoea	Recovery unless complicated by previous poor health or superimposed injuries or infections
30		Rapid emaciation Death (Mortality probably 50%)	

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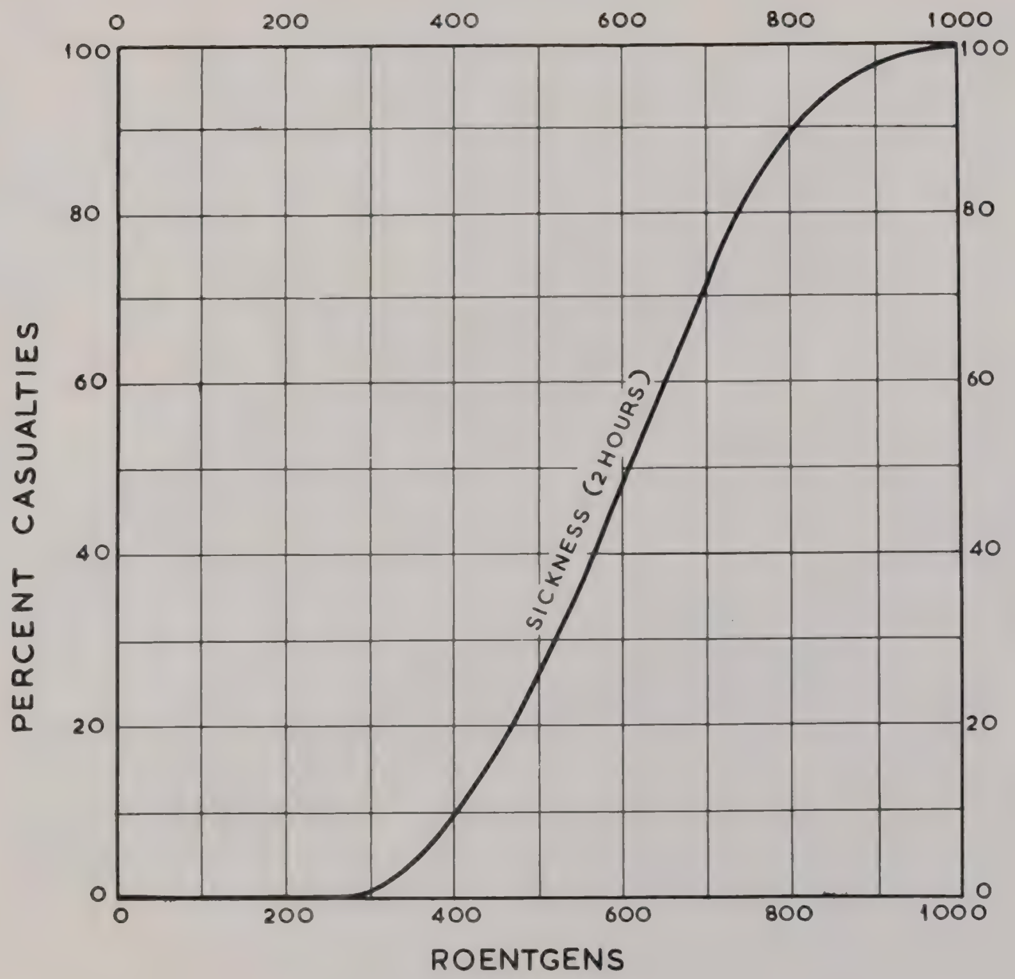

GAMMA RADIATION CASUALTIES
WITHIN 2 HOURS

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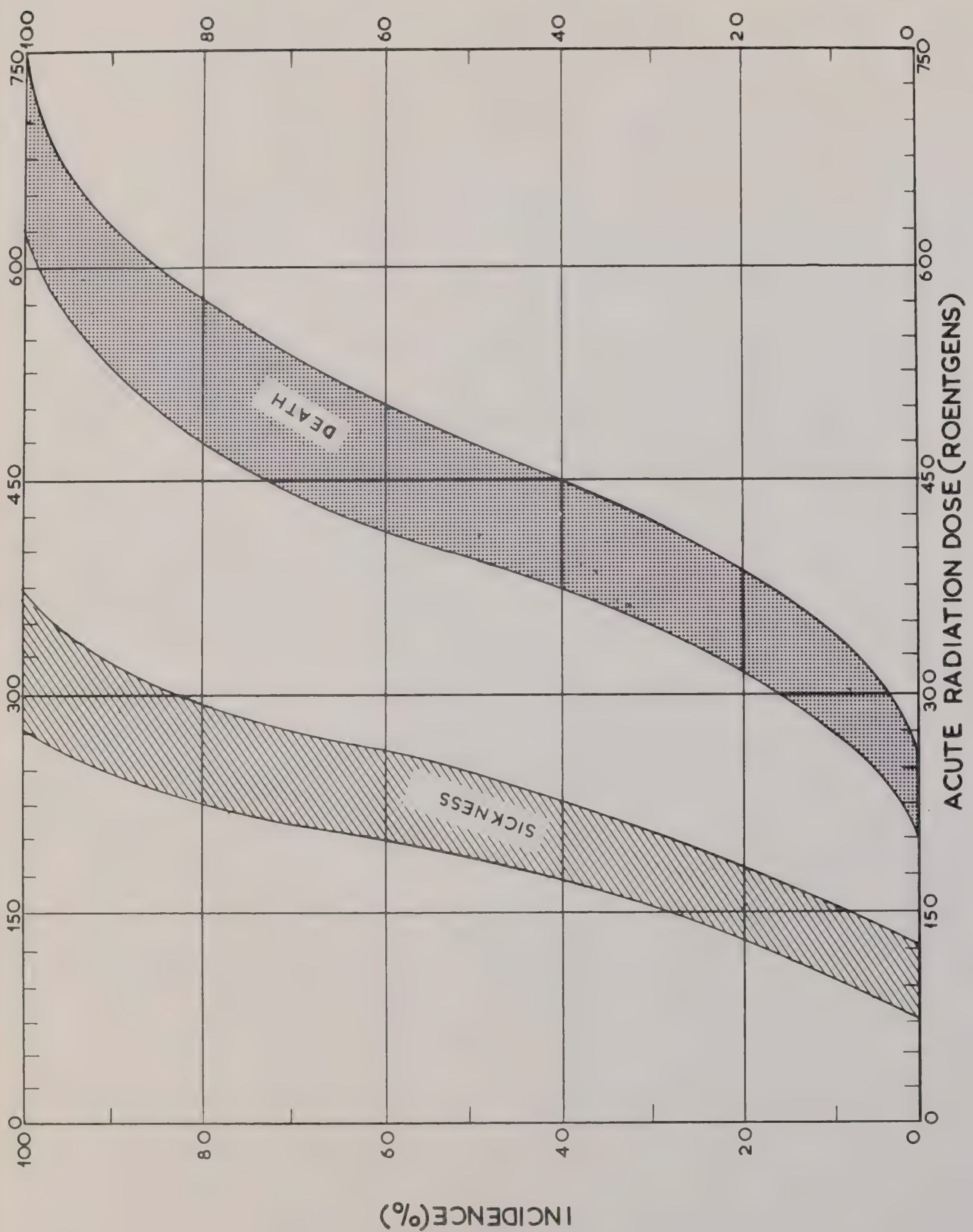

INCIDENCE OF SICKNESS & DEATH DUE TO ACUTE EXPOSURE
TO VARIOUS DOSES OF NUCLEAR RADIATION

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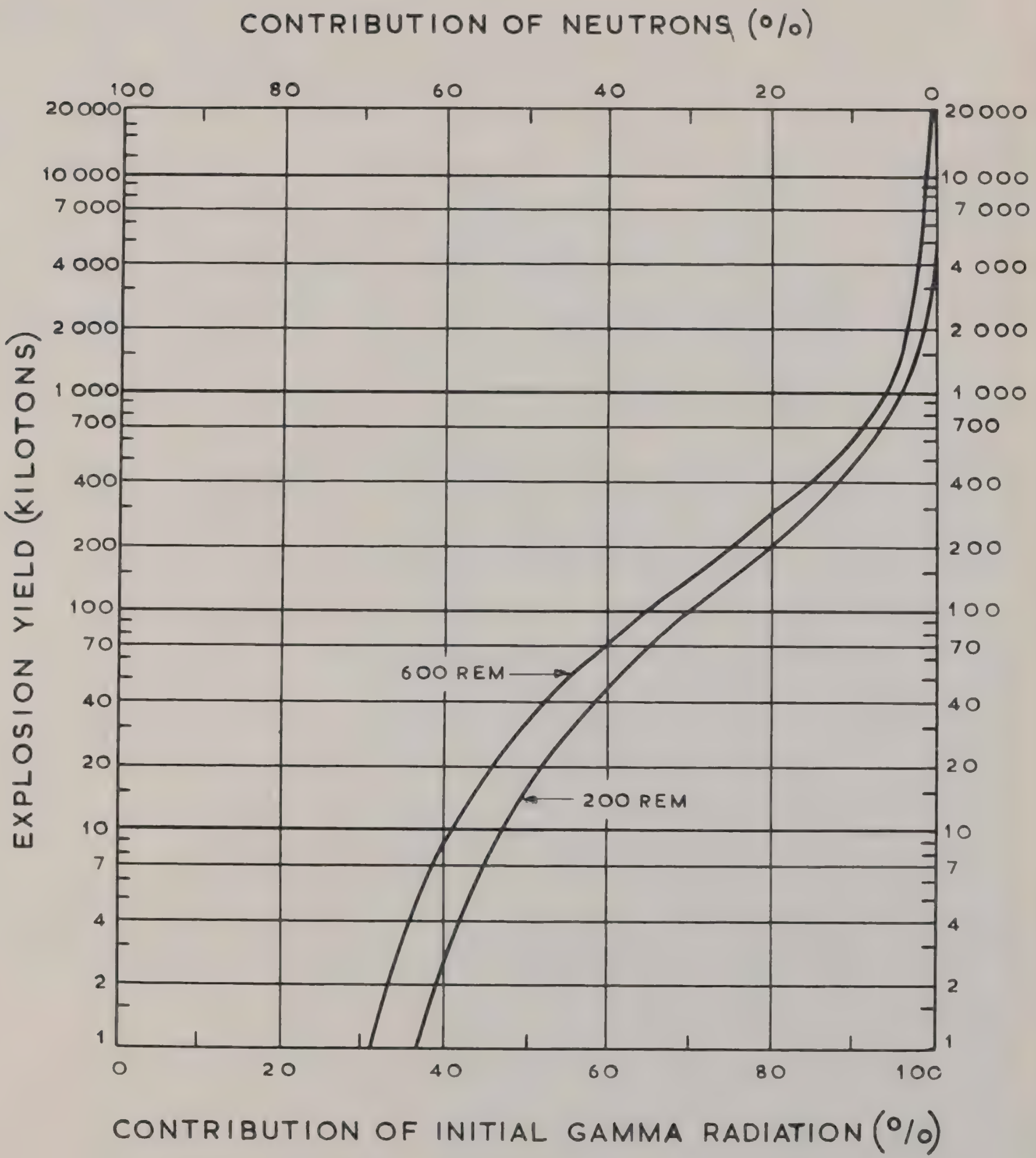

RELATIVE CONTRIBUTION OF NEUTRON AND
INITIAL GAMMA RADIATION TO TOTAL BIOLOGICAL DOSE

2.3. Effects on Man of External Residual Radiations

If radiation from surface contamination and fallout is to have any biological effect it must pass through the horny layers of the skin. Because of their very short range in air, and even shorter range (about 0.05 mm) in tissue, alpha particles are of no importance as an external radiation hazard.

Beta particles: These may penetrate a few millimetres in tissue, but do not reach the bone marrow or other inner parts of the body. Skin injuries ranging from reddening to blisters and sores may result from exposure to beta emitters, and these injuries can cause incapacity similar to that resulting from thermal burns. Depending on the dose received, the incapacity can begin as early as 4-6 hours, or as late as ten days, and the resulting injury may last for several months. The probability of exposed persons obtaining beta burns from fallout may be considerably reduced by immediate action such as bathing and change of clothing. The longer fallout remains in contact with the skin the more severe and extensive the beta burn is likely to be. Radiation sickness is not expected to accompany the skin injuries caused by beta particles. The acute effects of ionising radiation on the skin are given in Table 1, taken from Reference (1). The doses in this Table are expressed in 'rads', where 1 rad is by definition the unit of absorbed dose, and equals 100 ergs per gram of tissue.

TABLE 1

Acute Effects of Ionising Radiation on Skin

Estimated dose required in 1 week (rad)	Effect
0-600	No acute effects
600-2,000	Moderate early erythema
2,000-4,000	Early erythema under 24 hours. Skin breakdown in 2 weeks.
4,000-10,000	Severe erythema in 24 hours. Severe skin breakdown in 1-2 weeks.
10,000-30,000	Severe erythema in 4 hours. Severe skin breakdown in 1-2 weeks.
30,000-100,000	Immediate skin blistering (less than 1 day).

Gamma rays, being much more penetrating than alpha or beta particles, are the most hazardous type of external residual radiation. The mean energy of the gamma ray photons from residual radiations is about 0.7 Mev compared with about 3 Mev for initial gamma radiations. Residual gamma radiation is therefore less penetrating than initial radiation.

Little evidence is available of the ultimate effects of prolonged human exposure to moderate gamma radiation, such as might be experienced in a contaminated area, but the effects of tissue recovery may influence the degree of injury sustained. The total dose received is the basic criterion for injury to personnel; but if the time of exposure increases, then the total dose required to produce incapacity increases also. For example, on the average, 50 percent deaths would occur in persons exposed to an acute dose of 450r. On the other hand, exposure to 15r per day for 30 days would produce limited casualties and probably no deaths, (see Table 2, Chapter 2, Section 2.1). On a lesser scale of exposure it is expected that persons who received 0.1r daily for years would show no ill effects. In general, the clinical symptoms and biological effects of chronic doses of gamma radiation over the whole body are expected to be similar to those for acute doses, the severity of the effects increasing with dose rate and cumulative dose.

Reports on the effects on humans of accidental exposure to radioactive fallout from an atomic test are given in References (2), (3), (4) and (5). The incident in question was in March, 1954, when inhabitants of the Marshall Islands were exposed to fallout. Within about five hours of the burst, a radioactive white powder (consisting largely of lime produced by the thermal decomposition of coral) began to fall on the islands. The Marshallese spend much time out of doors and wear very little clothing, with the result that appreciable quantities of fission products fell upon and remained in contact with the hair and skin.

During the first 24 to 48 hours, a number of individuals experienced itching and burning of the skin. Within a day or two, all skin symptoms disappeared, but after a lapse of about two to three weeks, epilation and skin lesions were apparent on areas of the body which had been contaminated by fall-out particles. The lesions which developed on the exposed parts of the body not protected by clothing were mostly superficial, without blistering. Some individuals who were more highly contaminated developed deeper lesions, usually on the face or neck, accompanied by burning or itching and pain. These lesions were wet and ulcerated, becoming covered by hard dry scab. The majority healed readily, although in some cases about a year elapsed before the normal skin coloration was restored. Re-growth of hair of the usual colour and texture began in about nine weeks after exposure, and was complete in six months.

References

(1) Alpen, E. L., "Radiological Hazard Evaluation". 12th Tripartite Conference on Toxicological Warfare, (1957). (Secret/Discreet)

(2) Science, Vol. 122, No. 3181, p.1178, (1955) - "Radioactive Fallout in the Marshall Isles".

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(4) Cronkite, E. P., et al, "Response of Human Begings Accidentally Exposed to Significant Fallout Radiation". J.Am.Med.Assoc. Vol. 159, p.430, (1955).

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2.4. Effects on Man of Internal Radiations

Radioactive substances can enter the body by inhalation, ingestion, or through open wounds. Some may pass through the gut without being absorbed, others are absorbed but are rapidly lost through excretion, radioactive decay or a combination of both. The "biological half-life" is defined as the period of time during which the amount of a nuclide deposited in the body is reduced to half its initial value by natural biological processes. The "effective half-life" of a given nuclide is the time in which the quantity in the body will decrease to half as a result of both radioactive decay and biological elimination.

Those isotopes which are absorbed and remain in sufficient concentration and for sufficient time in certain organs may cause serious damage, e.g. I^{131} (a radioactive isotope of iodine with a half-life of eight days) concentrated by and held in the thyroid may cause acute and chronic damage to the gland. Sr^{90} (a radioactive isotope of strontium with a half-life of 28 years) deposited in bone may, after an interval of time, produce malignant changes. The amount of damage produced by radioactive materials inside the body will depend on the total amount of material taken up, its intensity of localization and its effective half-life.

The lymphocytes of the blood are sensitive to internal radiation, as also are the young red blood cells. The most sensitive indication of the acute effects of an ingested fission product is a reduction in the number of lymphocytes. An early systemic effect of a relatively large dose of internal radiotion would be a reduction in the number of red and white blood cells, associated with extreme weakness and anaemia. Malignant growths may later develop in those parts of the body where the radioactive material has concentrated.

Gamma rays penetrate tissues relatively easily and the dose from gamma emitting nuclides is fairly uniformly distributed except where there is a tendency for the nuclide concerned to localise in a particular organ, e.g. I^{131} in the thyroid. The emission of gamma rays from substances inside the body can be detected by externally placed instruments. Where mixed fission products from atomic weapons are involved beta particles will also be emitted and there may be alpha emitting substances. As with external radiations the more sensitive tissues, especially the blood-forming organs, are the most likely to be affected.

Beta particles have a short range but are very damaging within their effective range. Substances which emit them are therefore more dangerous when they localise in radio-sensitive organs. In particular there is a risk of severe anaemia, and where the nuclides concerned have a long biological half-life and localise in bone, malignant disease may occur. Strontium 90 and Yttrium 90, both beta emitters, are examples of bone-seeking elements.

Alpha particles are even more damaging than beta particles, but their range in air and tissue is shorter than that of beta particles. Like beta emitters, alpha emitting substances cannot be directly detected by external instruments, but their presence in the body may be demonstrated by detection of the radioactive material in the excreta, expired air, or in material obtained by biopsy. Certain alpha emitting substances are very liable to cause anaemia, and even when only a very small quantity is involved they may produce malignant changes in bone. Radiu, uranium and plutonium are examples of bone-seeking alpha emitters.

Experiments on rats have shown that plutonium is 20 times more effective than radium in depressing the bone marrow function. This is apparently owing to the fact that plutonium is deposited in the surface layers of the bones rather than in the substance, and consequently its effect is more severe on the bone marrow and periosteum.

It is known from human experience that if radium is present in the bones for a long period it produces general weakness, bone changes in the jaw, malignant tumours, and bone cancer (osteogenic sarcoma). Animal experiments have shown that radiostrontium has very similar effects, and may also induce leukaemia. There is no evidence from human experience of the toxicity of radiostrontium.

Recent publications dealing with the Strontium-90 problem are given in References (1), (2), (3) and (4).

References

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CHAPTER 3 - CRITICAL DOSES AND CONTAMINATION LEVELS

3.1 Initial Radiation

Initial radiations from nuclear explosions are discussed in detail in Chapter 5 of M.E.A.W. (Reference (1)), which should be consulted for general data and background information. The purpose of this Section is to provide data relating critical doses of initial radiation (gamma rays and neutrons) to weapon yields and conditions of burst. The incident flux of initial radiation will be determined by the type and yield of the weapon, the heights of the burst and of the target, and the distance from the explosion.

Gamma radiation. Air density is the controlling factor for the attenuation of gamma radiation. The relation between initial gamma radiation dose and distance for various relative air densities is given in Figures 1A and 1B, which refer to a 1 KT air burst. The attenuation of gamma radiation by the air is reduced by the rarefaction which occurs behind the blast wave. This effect (also known as the hydrodynamic effect) may be corrected for by using Figures 2A and 2B, which give the scaling of initial gamma radiation with yield, and are obtained from Reference (2). The rarefaction effect is negligible for bursts up to 50 KT but assumes major importance in the high yield range above about 200 KT. Some values, which include corrections for typical heights of burst, are given in Part I, Appendix A, paragraph 3.4 (bound with figure 2).

For a surface explosion in the KT range, the losses due to absorption of gamma radiation and neutrons in the ground will cause the dose to be rather less than is observed for an air burst in so far as an observer on the ground is concerned. But note that for an observer in aircraft above the burst the dose will be twice that given by Figures 1A and 1B. For a surface explosion in the high yield range (greater than about 200 KT), the rarefaction effect will cause the doses to be about the same, or possibly more than would be observed for an air burst.

Information relating initial gamma dose to slant range for a 1 KT sub-surface burst is given in Figure 3, which should be used in conjunction with Figures 2A and 2B. Both sub-surface and surface bursts produce extensive fallout, and in such regions the initial gamma dose may merge with that due to residual radiation.

The percentage of gamma radiation dose received as a function of time is given in Figure 4 for kiloton air bursts, in Figure 5 for kiloton surface bursts, Figure 6 for megaton surface bursts, and Figure 7 for kiloton sub-surface bursts. These figures are taken from Chapter 5 of Reference (1)

It will be noted that for kiloton range weapons about half the gamma-rays dosage is received during the first second. Therefore at distances of the order of 4,000 feet where a dose of about 400 roentgens would be received by a fully exposed person, taking shelter behind a substantial object immediately on seeing the bomb flash, might cause a vital reduction in the dose received. Opportunity for evasive action would be greater in the case of megaton weapons since the delivery is slower.

Neutrons. Although the neutron intensity will normally be sub-lethal at distances for which a median lethal dose of gamma rays would be received, the biological effect of the neutrons will be additive to that of the gamma radiation. However, at a sufficiently high altitude (greater than about 25,000 feet) the dose from neutrons may become more important than the

initial gamma radiation dose. Figure 8 represents the maximum expected neutron dose, and Figure 9 the minimum dose, depending on the weapon design, for a 1 KT air burst at various air distances. These values may be scaled directly with yield up to 100 KT, but above this figure estimates based on linear extrapolation must be used with caution. In the case of a surface burst the proportionate doses will be changed in rather the same way as gamma radiation, but again no precise data are available. The neutron dose from a sub-surface shot will be negligible.

Figure 10 shows the number of neutrons per sq.cm. expected at various slant distances for weapon yields from 10 KT to 40 MT for air burst weapons. This figure is taken from Reference (2) and is qualified by the statement that in the case of certain high neutron flux weapons there may be as many as thirty times the given number of neutrons per sq.cm.

The neutron hazard to man is estimated from two kinds of experimental measurements. Firstly, the physical data concerning the neutron flux and energy spectrum are obtained from the use of neutron detectors. Secondly, account is taken of the biological effects of exposing animals (mainly mice) to neutron fluxes ranging from harmless to lethal. The results obtained are coupled by factors for the RBE of neutrons of various energies when compared with X and gamma rays, and it is further assumed that these results may be applied to man. Work on these lines has led to the following conclusions by U.S. workers (Reference (3)).

Neutron Energy	Dose in rem/n/cm^2
0 - 0.4 ev	5.9×10^{-11}
<1 Mev	Proportional to and decreasing with energy
1 - 3 Mev	1.6×10^{-8}
3 - 15 Mev	2.0×10^{-8}

In calculating the doses for neutron energies greater than 1 Mev, an RBE of 4 was assumed. It was observed during the U.S. experiments (Reference (3)) that for all weapon tests at which biological measurements were made, over 90% of the dose was from neutrons with energy above 1 Mev. Neutrons in the energy range 3 - 15 Mev (for which sulphur was employed as detector) contributed 25-50% of the dose, and those in the intermediate (approximately 1-3 Mev) range, 50-75%. The slow neutrons, with energies less than about 1 ev, contributed no more than 2% of the total neutron dose received at distances of biological interest.

Most of the neutrons reaching the ground would do so in such a short space of time (less than 1 second), that evasive action would not be possible.

Further discussion of neutron energies and lethality is given in Chapter 5, Section 5.2, which deals with neutron shielding problems. An unclassified account of the neutron energy spectrum of nuclear explosions is given in Reference (4).

References

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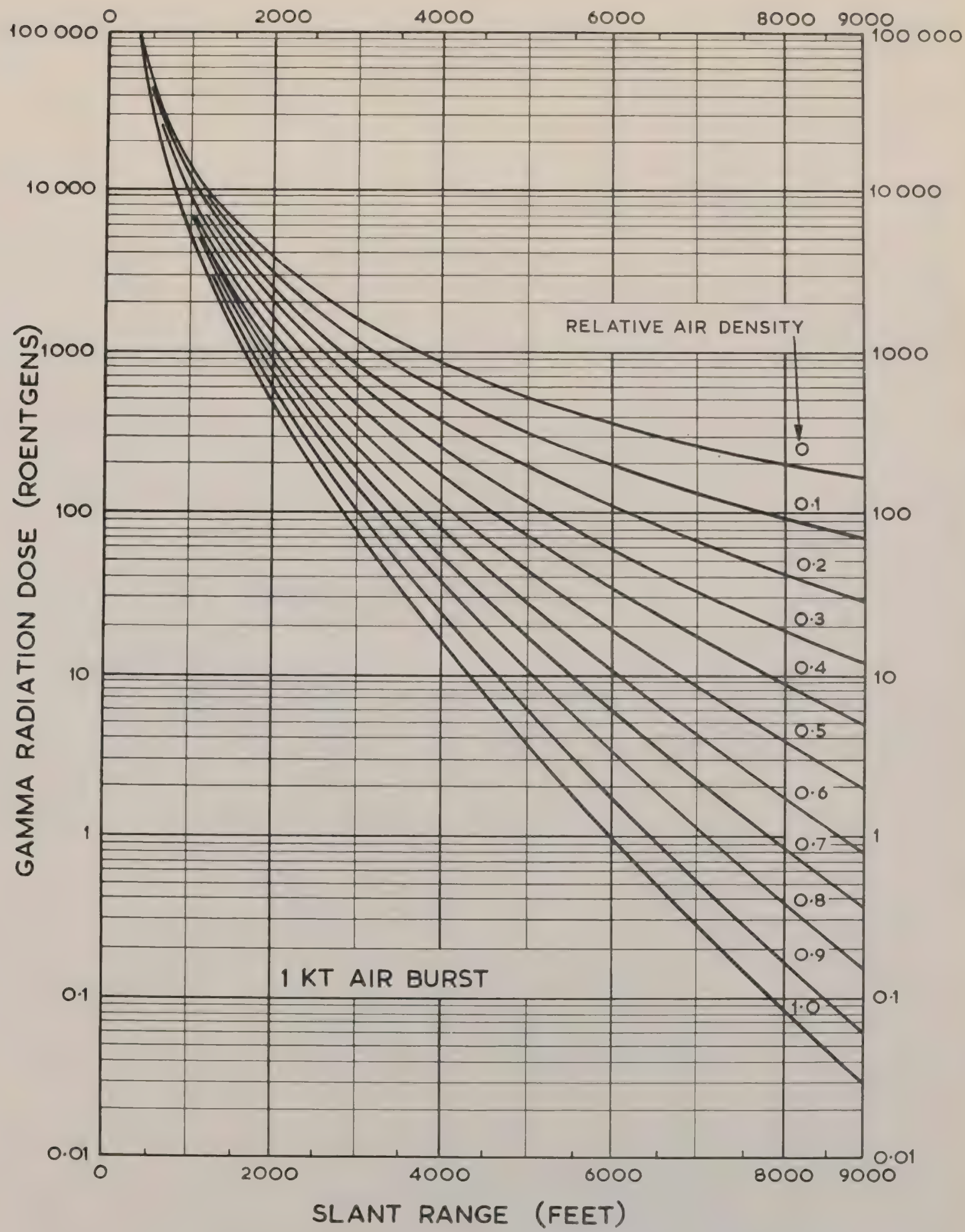

INITIAL GAMMA RADIATION DOSE AS A FUNCTION OF SLANT RANGE FOR VARIOUS RELATIVE AIR DENSITIES

PART VII
CHAPTER 3
SECTION 3.1
FIGURE 1 B

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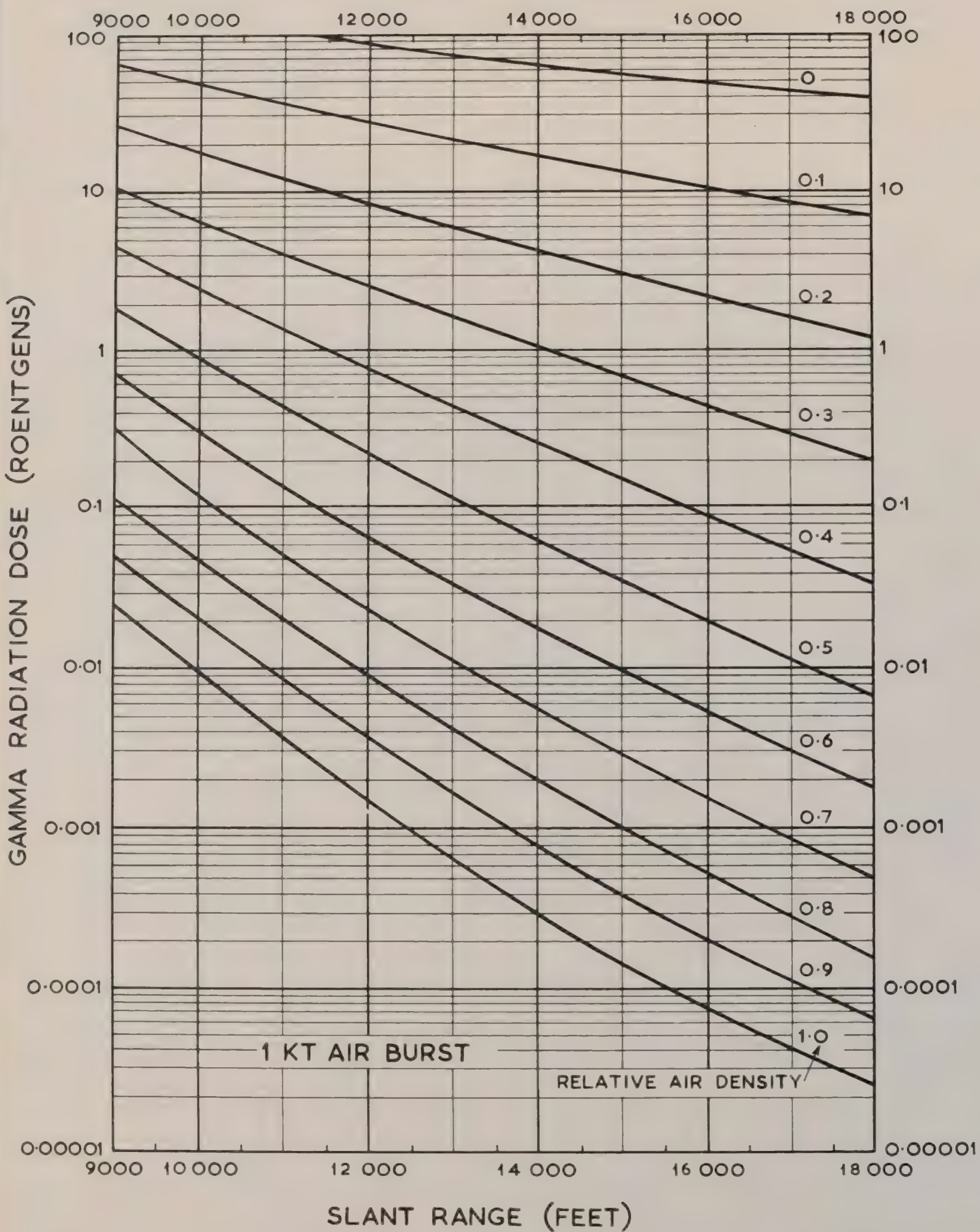
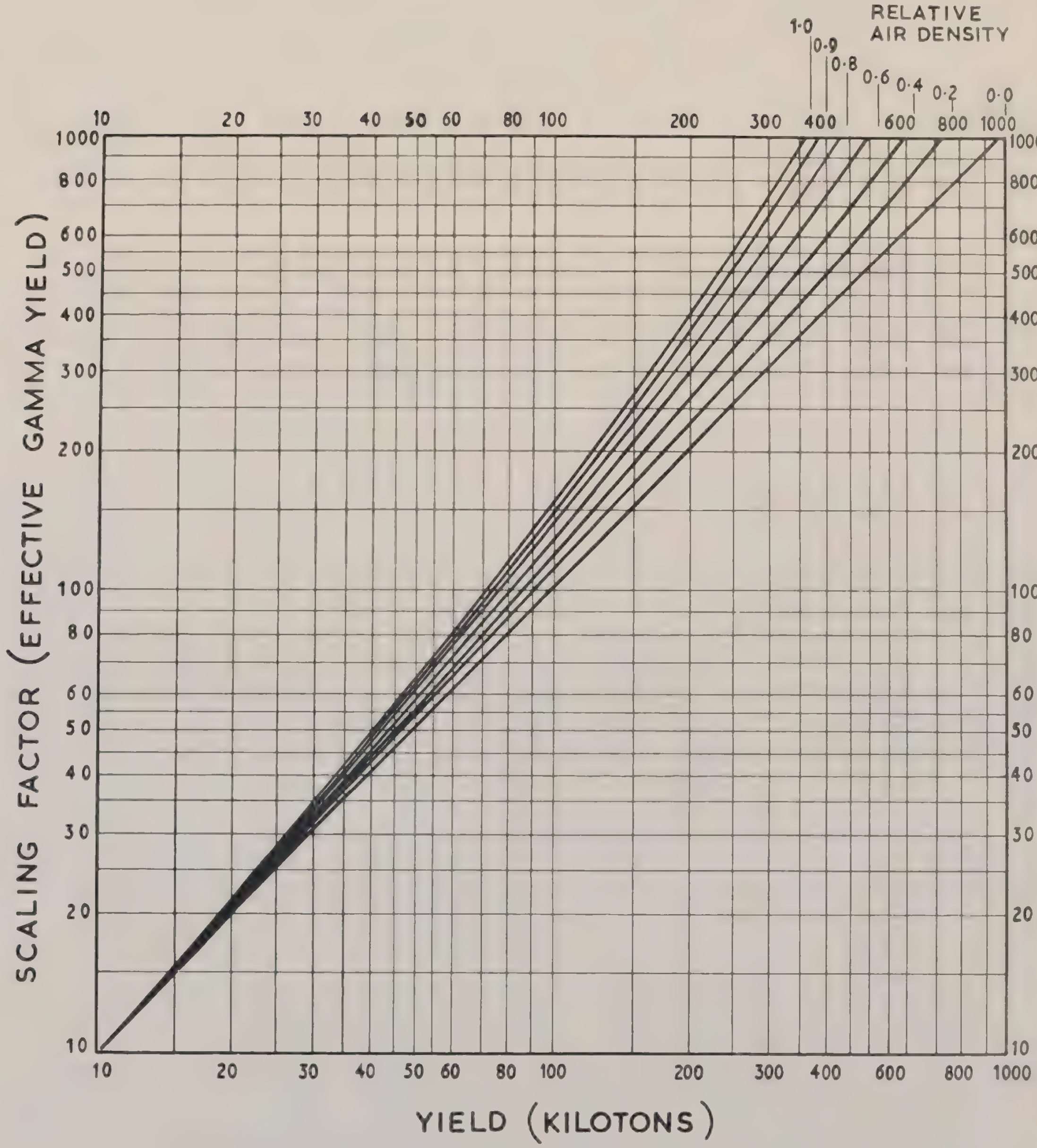
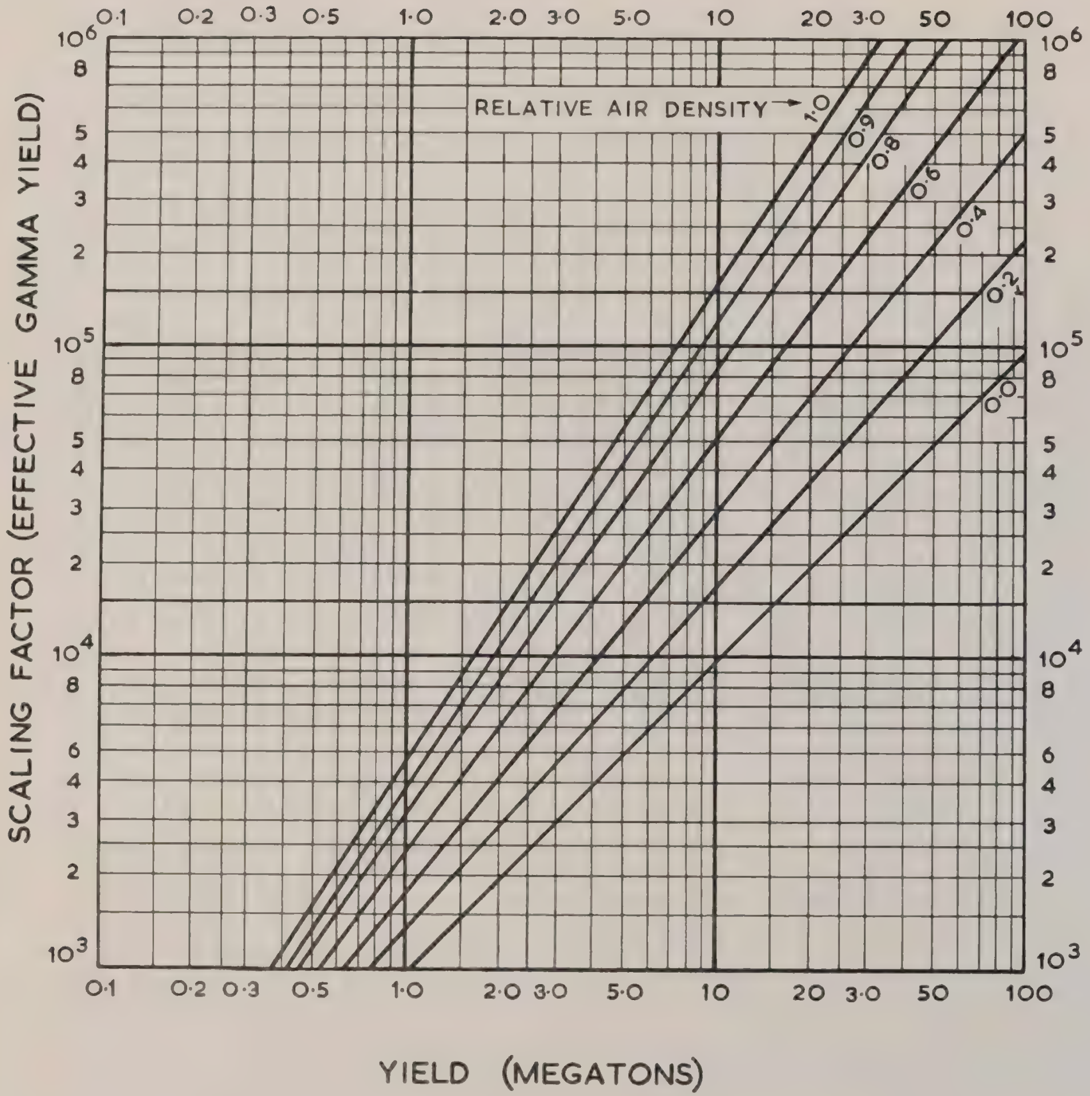


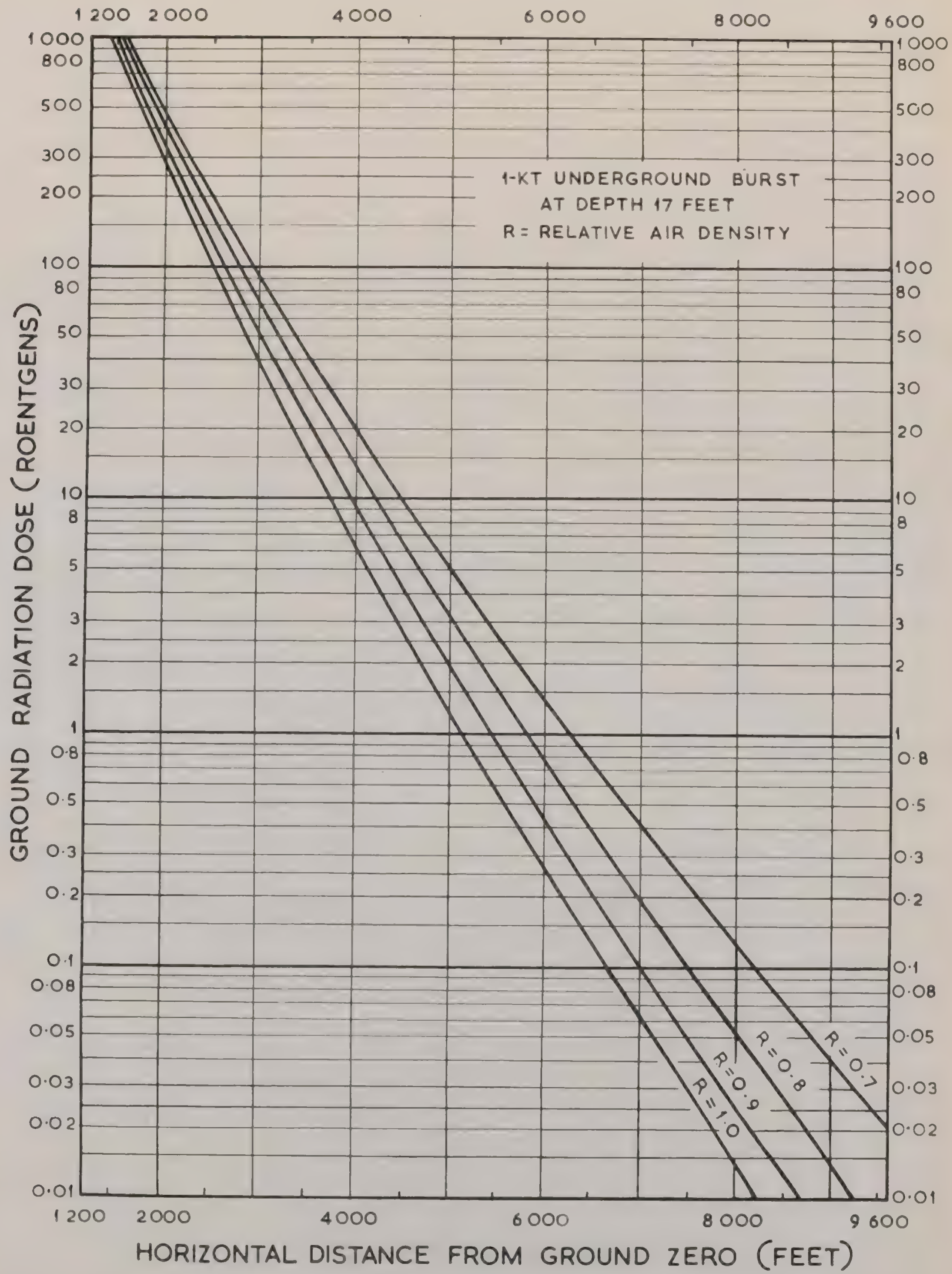
INITIAL GAMMA RADIATION DOSE AS A FUNCTION OF SLANT RANGE FOR VARIOUS RELATIVE AIR DENSITIES



SCALING OF INITIAL GAMMA RADIATION WITH YIELD



SCALING OF INITIAL GAMMA RADIATION
WITH YIELD



INITIAL GAMMA DOSE/DISTANCE CURVES FOR
1-KT UNDERGROUND BURST

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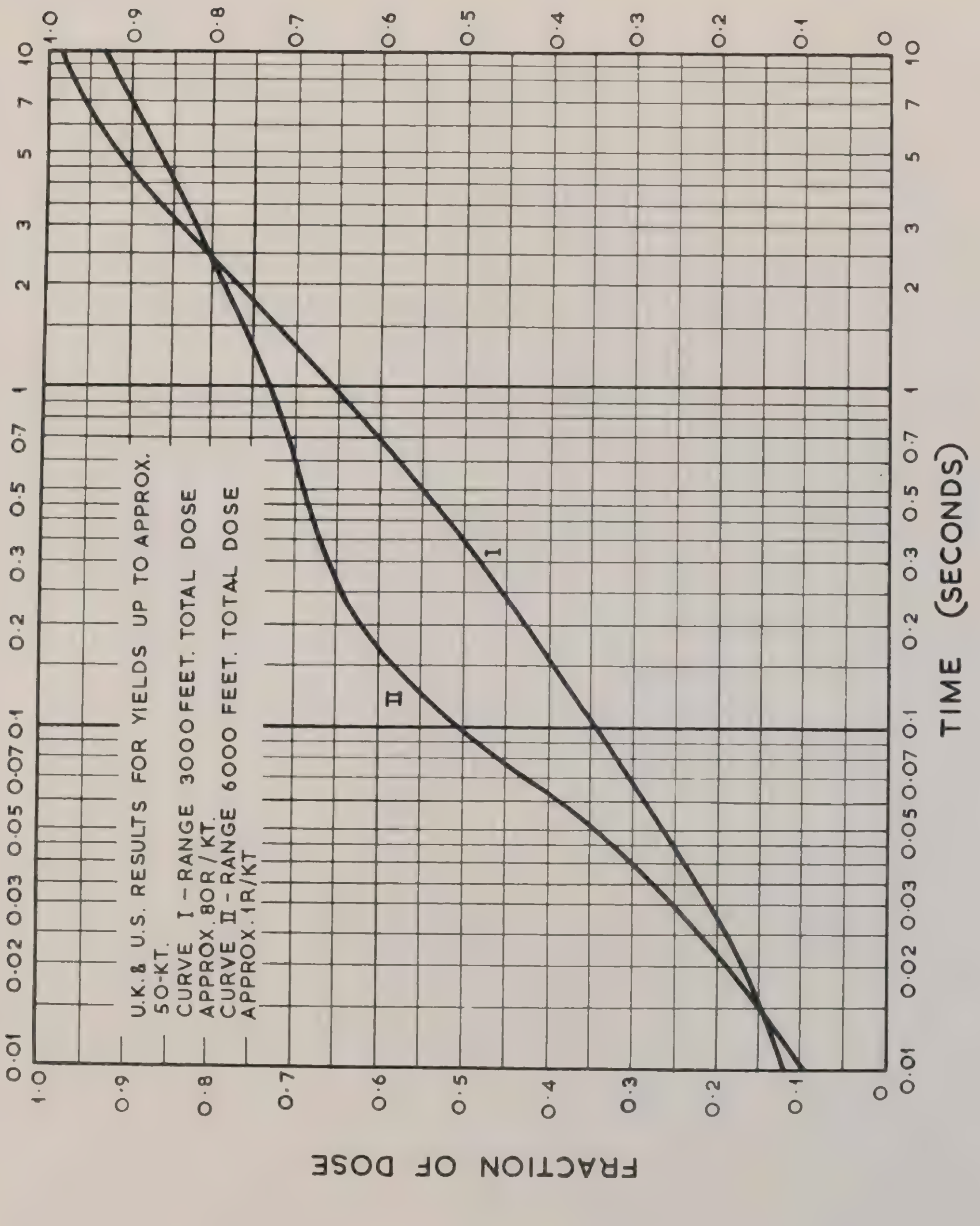
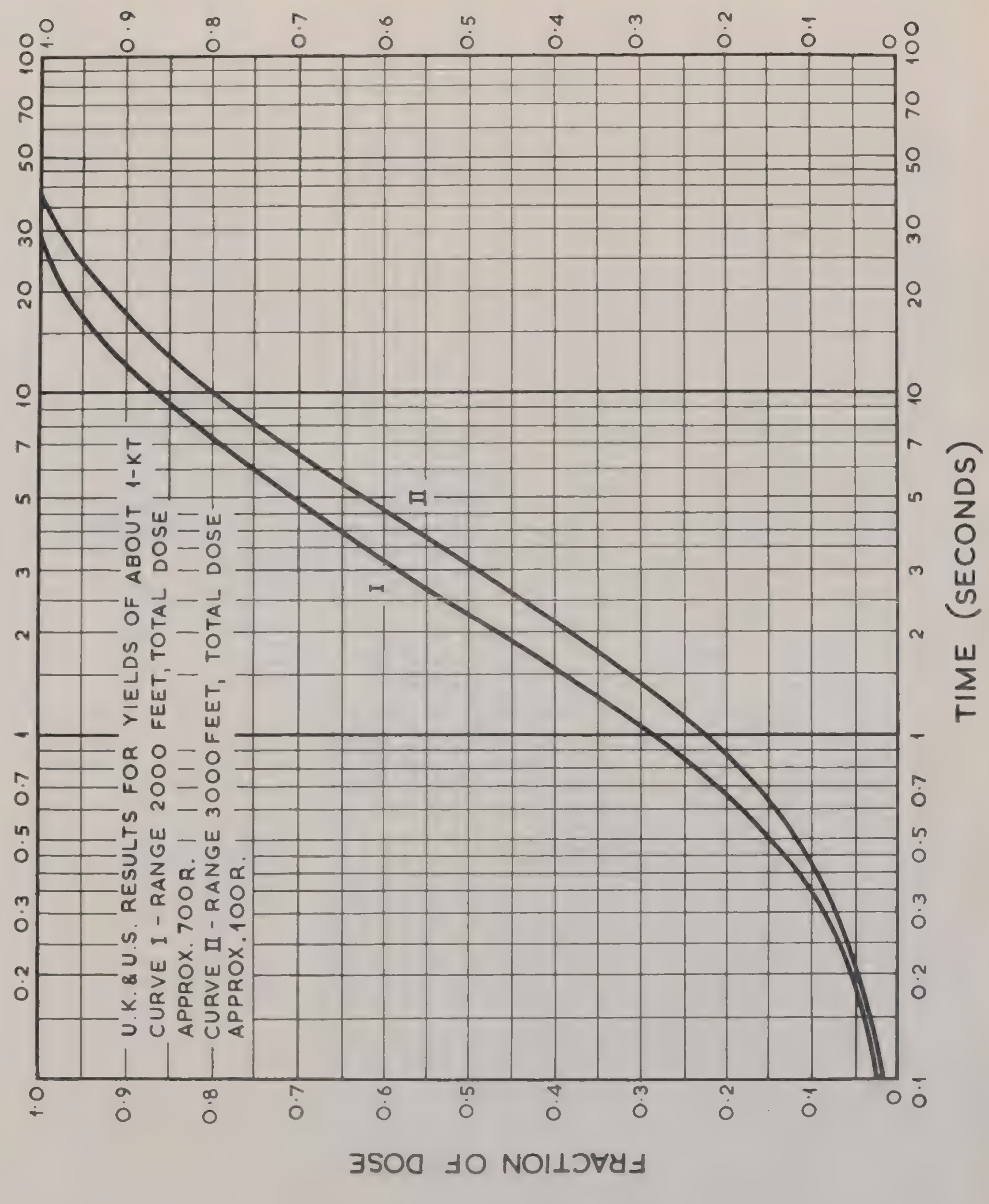


DELIVERY OF GAMMA DOSE IN TIME
AIR BURST



DELIVERY OF GAMMA DOSE IN TIME
SURFACE BURST

SECRET / ATOMIC
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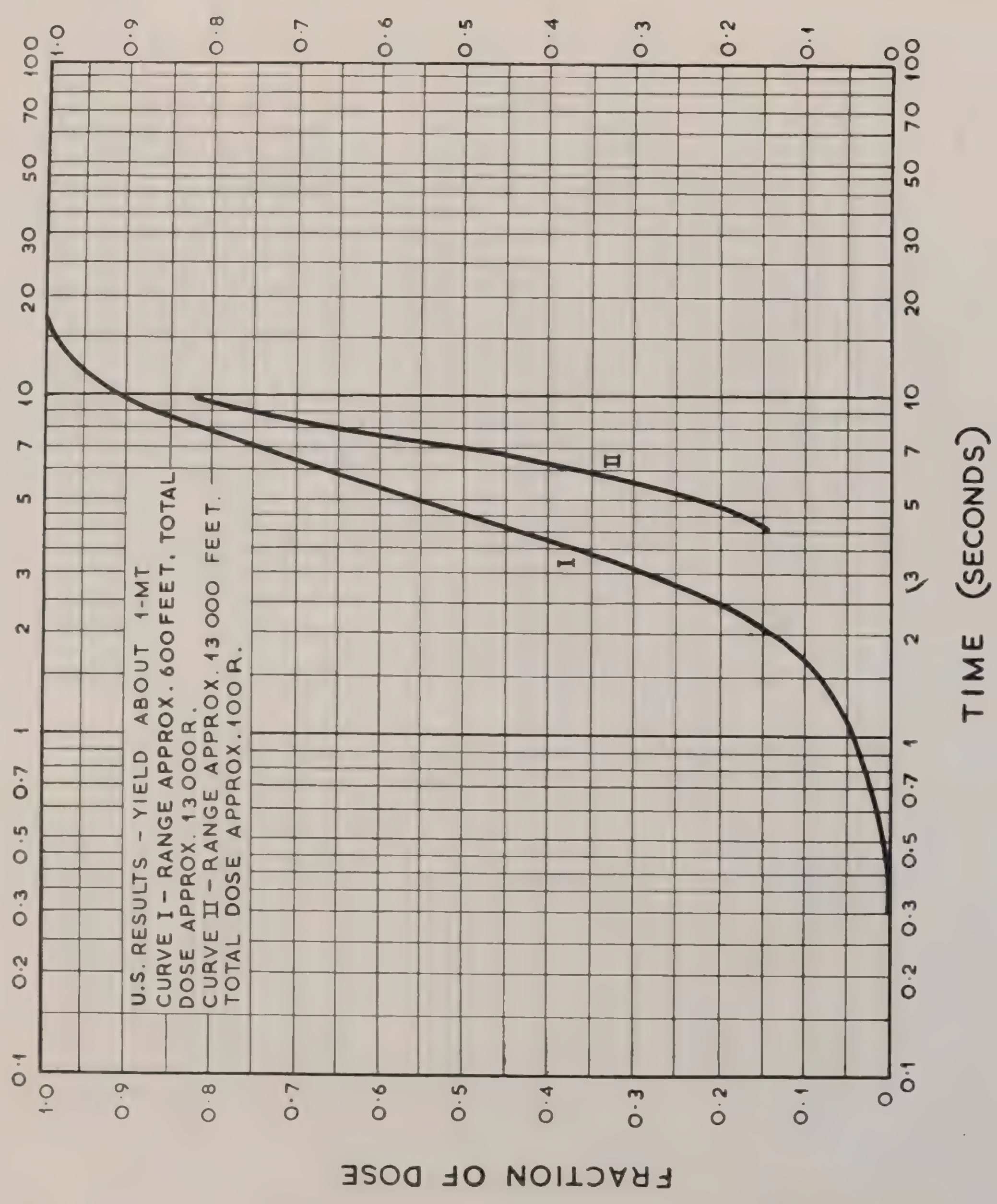
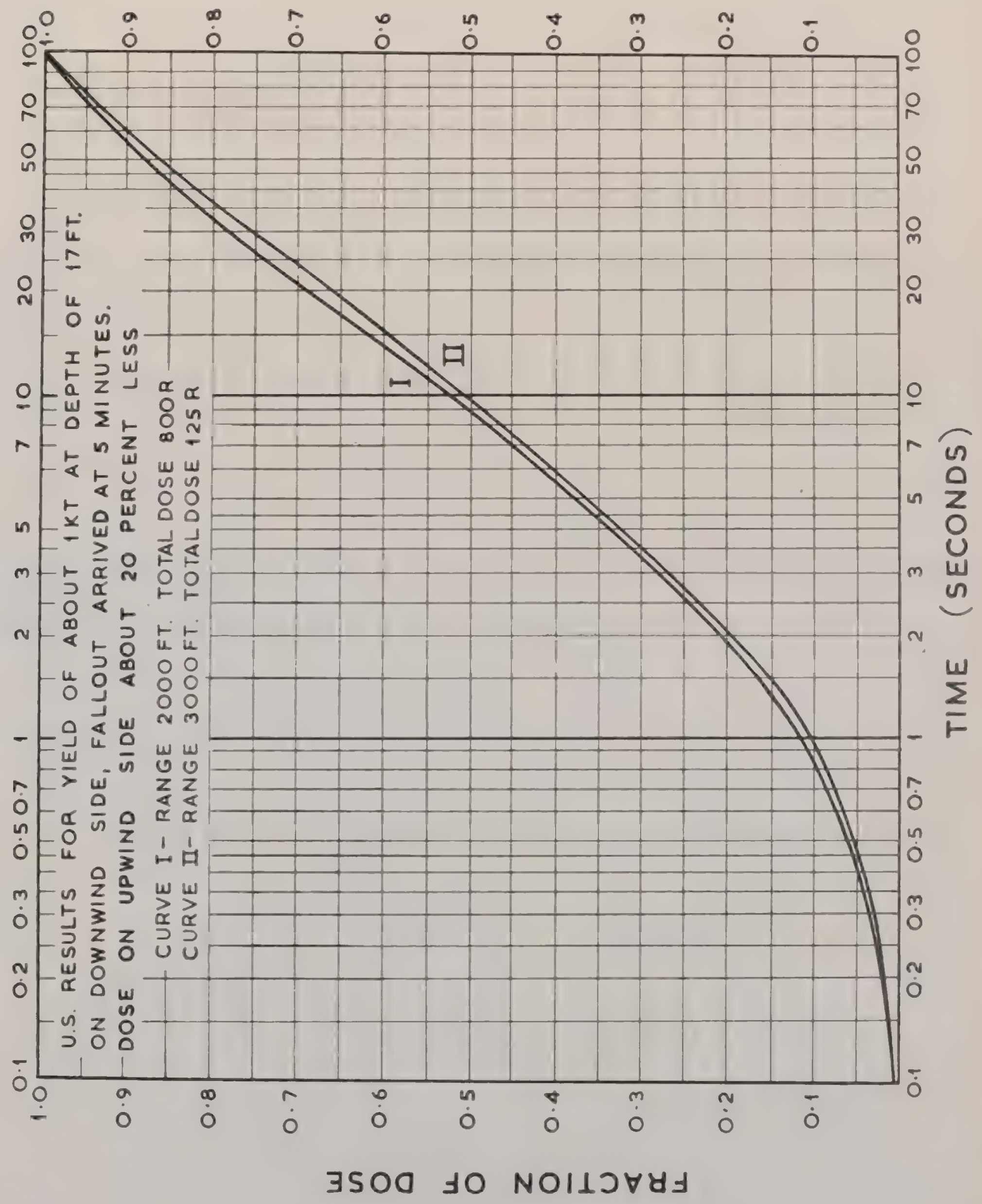
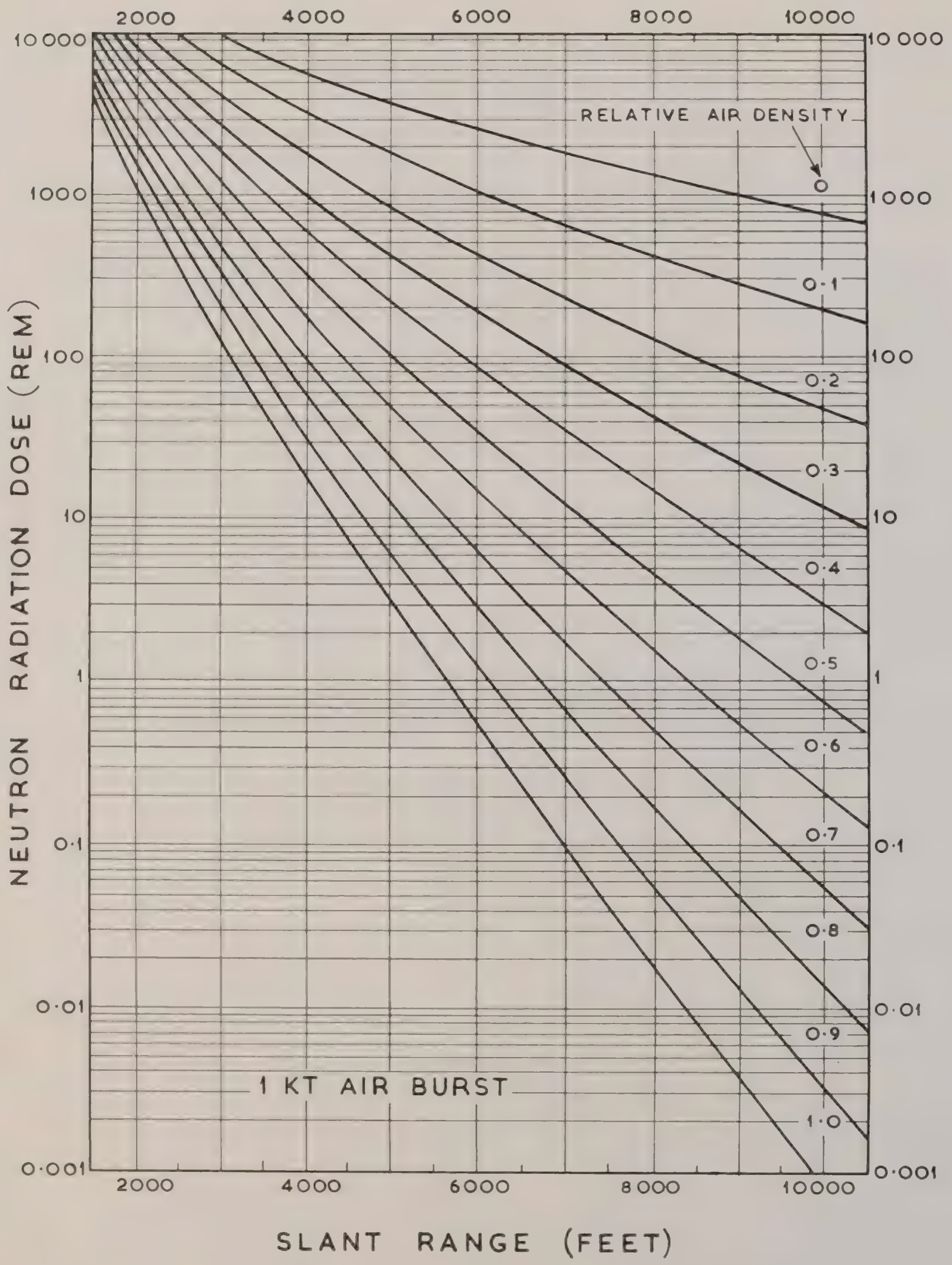


DELIVERY OF GAMMA DOSE IN TIME
HIGH YIELD SURFACE BURST



DELIVERY OF GAMMA DOSE IN TIME
SUB – SURFACE BURST

CONFIDENTIAL
ATOMIC



NEUTRON RADIATION DOSE AS A FUNCTION OF SLANT RANGE (HIGH NEUTRON FLUX WEAPONS)

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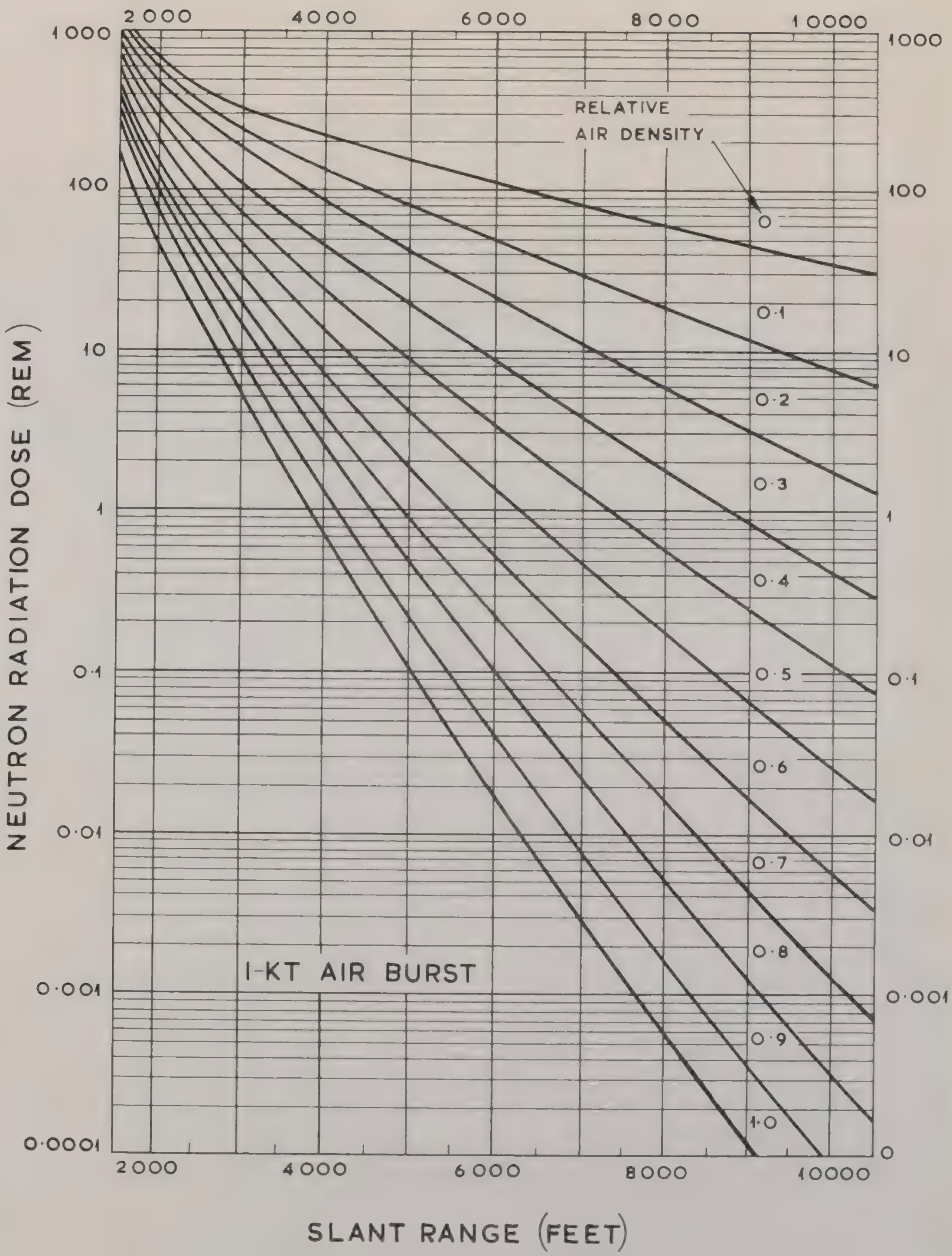

NEUTRON RADIATION DOSE AS A FUNCTION OF SLANT RANGE (LOW NEUTRON FLUX WEAPONS)

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ATOMIC

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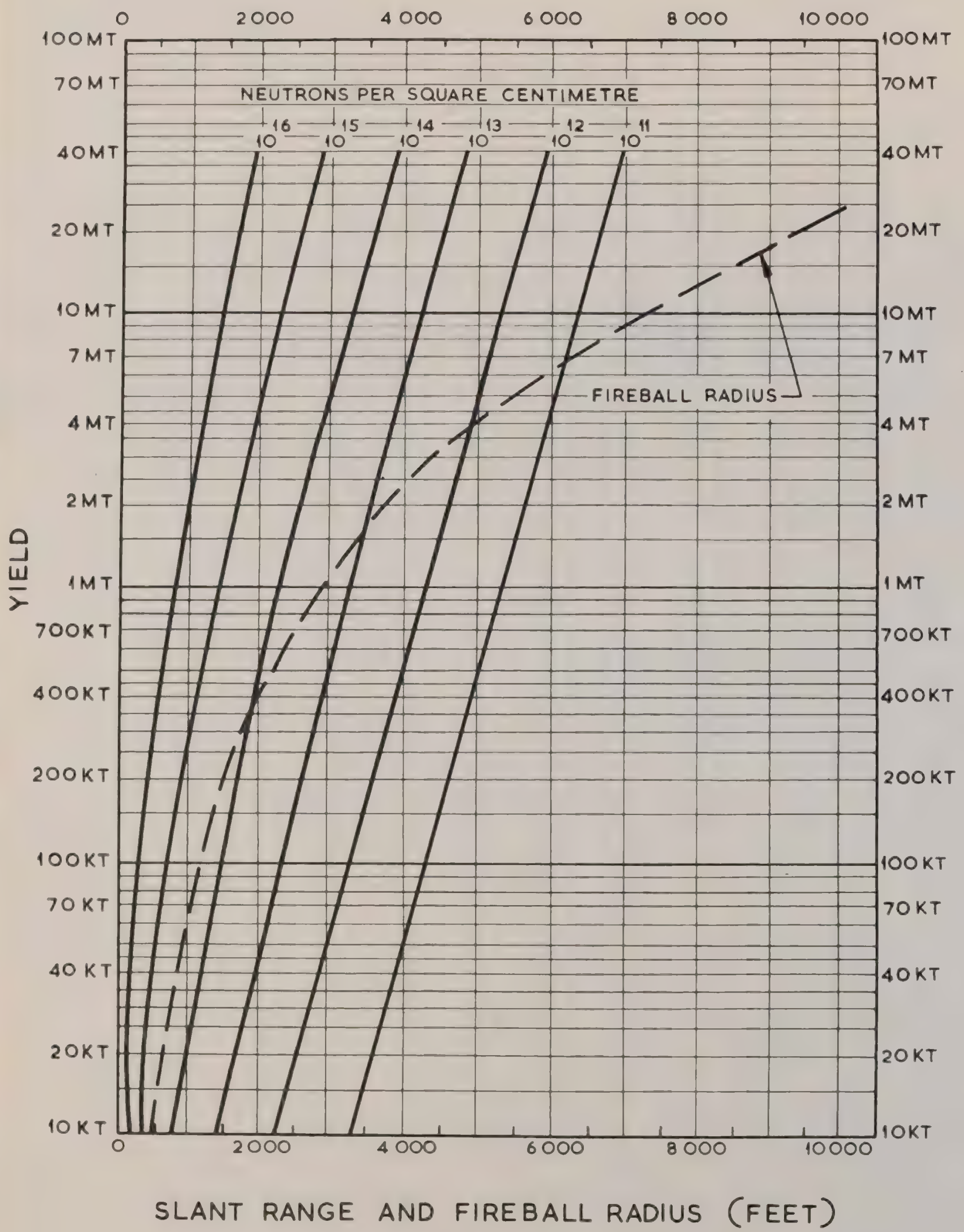


FREE AIR NEUTRON FLUX

CONFIDENTIAL/ATOMIC

3.2 External Residual Radiations

Residual nuclear radiations are defined as those emitted after one minute from the time of burst of an atomic explosion. They arise from three sources:-

(a) fission products from the explosion;
(b) uranium or plutonium which has escaped fission in the explosion;
(c) activity induced by neutrons in elements present in the earth or sea.

In the case of a high air burst weapon the residual radiations would arise mainly from fission product activity, but a very low or surface burst would cause significant neutron-induced activity at the surface, as well as additional fallout from the material carried up from the surface.

The distribution of contamination from fallout is fully treated in Chapter 7, but it may be said here that in the case of a high air burst the bomb cloud carries nearly all the radioactive bomb debris to high altitudes and by the time this material falls back to earth dilution and radioactive decay will have decreased the activity to a very low level. An exception may occur in the case of a small yield weapon burst in the rain. For yields of about 8 KT and below, rain-out of radioactive material can be a hazard to personnel situated downwind and outside the danger area of initial radiations and other effects. Although weapons of greater yield produce more radioactive material, the more powerful up-currents take the bulk of this material up to an altitude above the level of precipitation.

For a surface burst the fallout in the vicinity of the explosion is a considerable hazard, as roughly half the total residual radioactivity will be deposited on the ground within a few hundred miles of the burst point.

Figure 1 gives the total radiation dose received in a contaminated area as a function of time, Reference (1). This is usually considered a gamma hazard, the associated beta hazard being normally negligible, except in the case of a person lying on contaminated ground. When much of the relatively penetrating gamma radiation is screened, e.g. by earth or buildings, a higher proportion of the dose received at a given point may be from local beta activity. Under such conditions, Radiac survey meters may give misleading under-estimates of the local dose rate if they are of the type which is sensitive only to gamma radiation (see Chapter 9, Section 9.3).

Figure 2 relates fission product decay factors with time after the explosion (Reference (1)). For example, if the dose rate at one hour after the explosion is known, the rate at any other time may be calculated. Alternatively, the decay curve may be used to determine the value of the dose rate at one hour, from the rate at a later time. See also References (2) and (3) for further details.

A useful method for determining the age of fission products is illustrated in Figure 3, (Reference (4)).

Figure 4 gives the neutron-induced gamma activity at Ground Zero for air burst weapons of various types, at a reference time of one hour after a burst of 1 KT yield, Reference (1). The activity induced, and the decay rate, will vary according to the soil composition.

This induced activity is influenced most strongly by the sodium content of the soil, the sodium being converted by neutrons to radioactive Na^{24}, which has a half-life of 14.8 hours. This isotope emits beta particles with average energy about 0.5 Mev and gamma ray photons of 1.4 and 2.8 Mev energy.

Another source of induced activity is manganese which, being an element that is essential for plant growth, is found in most soils, even though in small proportions. As a result of neutron capture the radio-isotope Mn^{56}, with a half-life of 2.6 hours, is formed. It gives off several gamma rays of high energy, and also beta particles. Mn^{56} loses its activity more rapidly than Na^{24}, but during the first few hours after an explosion, the manganese may constitute a more serious hazard than sodium. Aluminium, a common constituent of soil, can form the isotope Al^{28}, but since its half-life is only 2.4 minutes, very little remains one hour after the explosion. Sea water contains about 3 per cent sodium chloride, and an atomic explosion near to the surface or under water will produce substantial quantities of Sodium-24. Also formed is a radio-isotope of chlorine, Cl^{38}, which has a half-life of 38.5 minutes.

Neutrons from a nuclear explosion may also be captured by nuclei contained in structural and other materials. Among the metals, the chief sources of induced radioactivity are probably zinc, copper and manganese, the latter being a constituent of many steels, and, to a lesser extent, iron. Wood and clothing are unlikely to develop appreciable activity, but glass could become radioactive because of its large sodium and silicon content. Foodstuffs can acquire induced activity, mainly as a result of neutron capture by sodium. However, at distances from a nuclear explosion at which this activity would be significant the food would probably not be fit for consumption on account of fire and blast damage. (Further details on this subject are given in Section 3.3 of this Chapter).

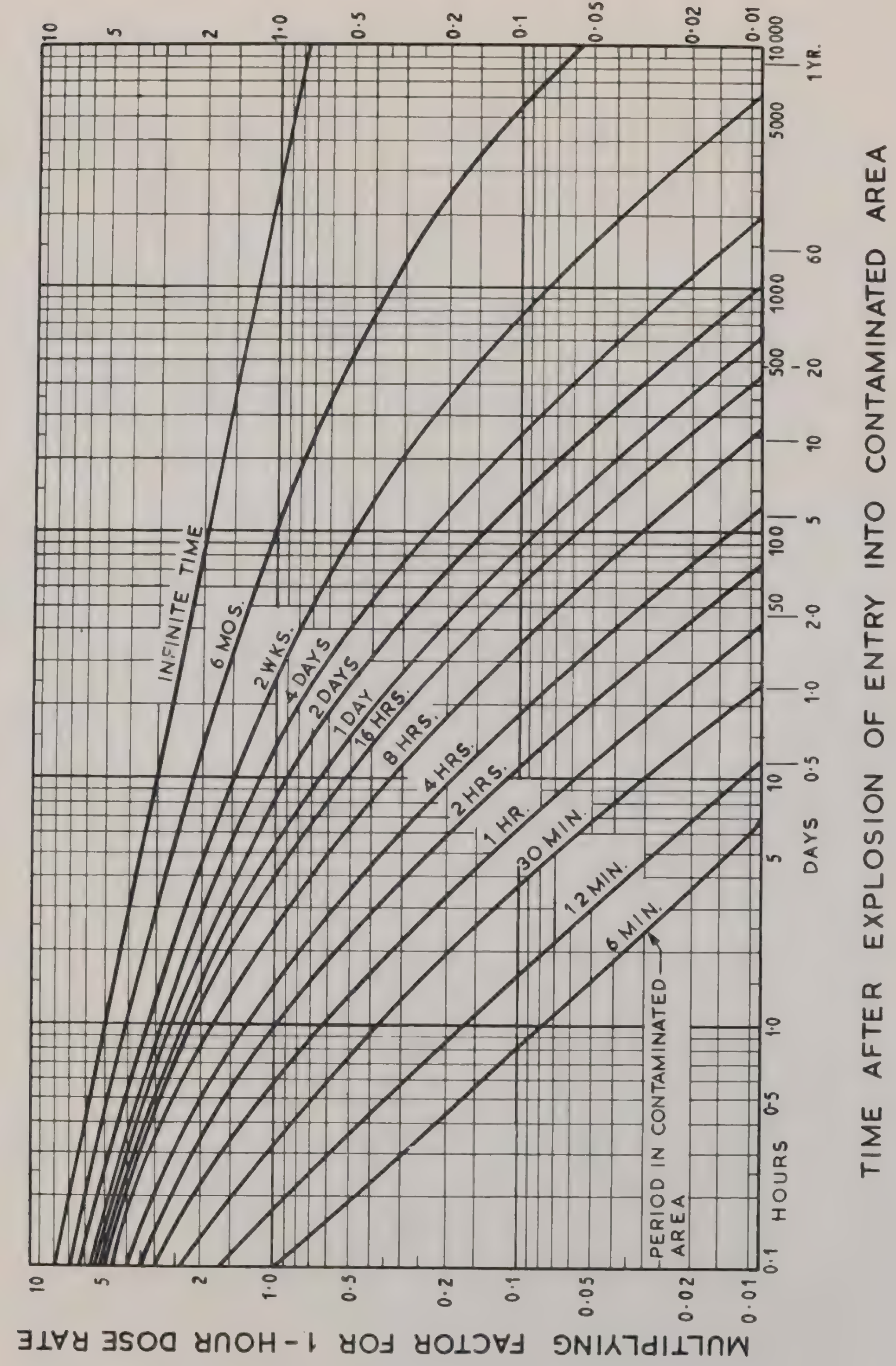
References

(1) Capabilities of Atomic Weapons, A.F.S.W.P. TM23-200 (1955) (Confidential/Atomic)

(2) A.W.R.E. Report No. O-35/56(X) - "Dose Rates from Ground Contaminated with Residual Radioactive Materials from an Atomic Explosion" (Official Use Only)

(3) Radiology, Vol. 66, pp 585-94, April, 1956 - "Criteria for Evaluating Gamma Radiation Exposures from Fallout Following Nuclear Detonations" by G. M. Dunning.

(4) U.S. Air Force Special Weapons Centre. Report AFSWC-TN-56-2, (1956)



TOTAL RADIATION DOSE RECEIVED IN A CONTAMINATED AREA

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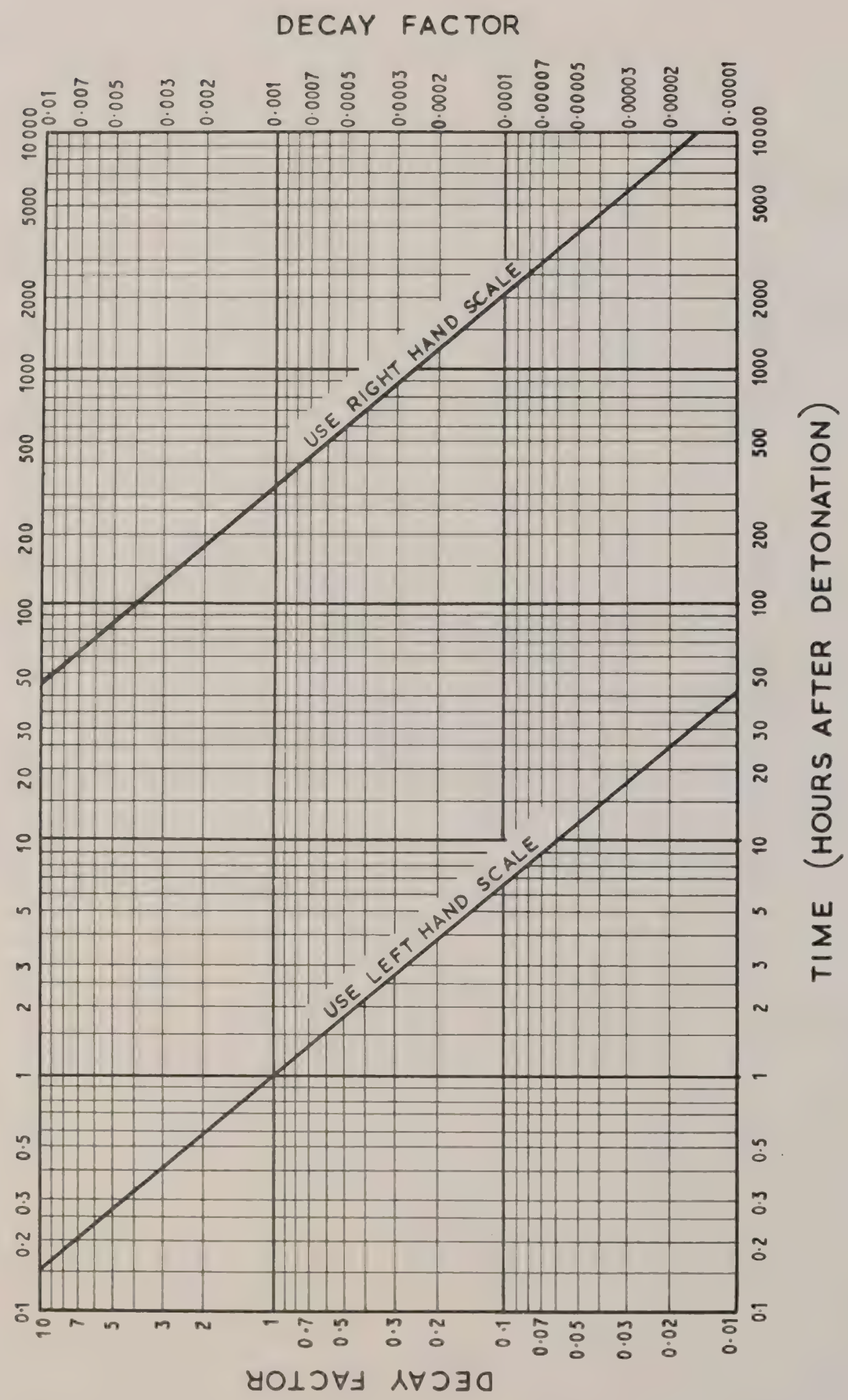
D.N.W.
FEB. 1958



FISSION PRODUCT DECAY FACTORS FROM ONE HOUR AFTER DETONATION

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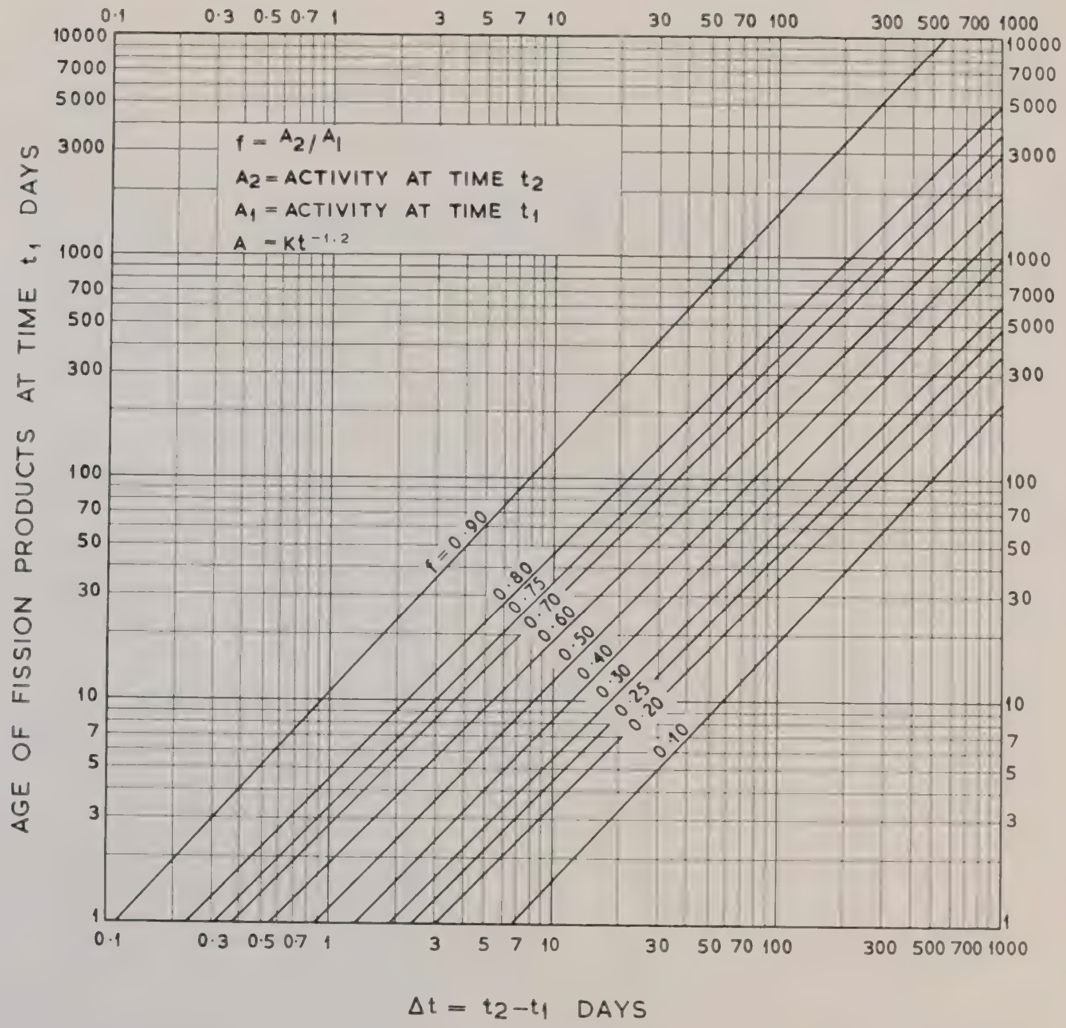
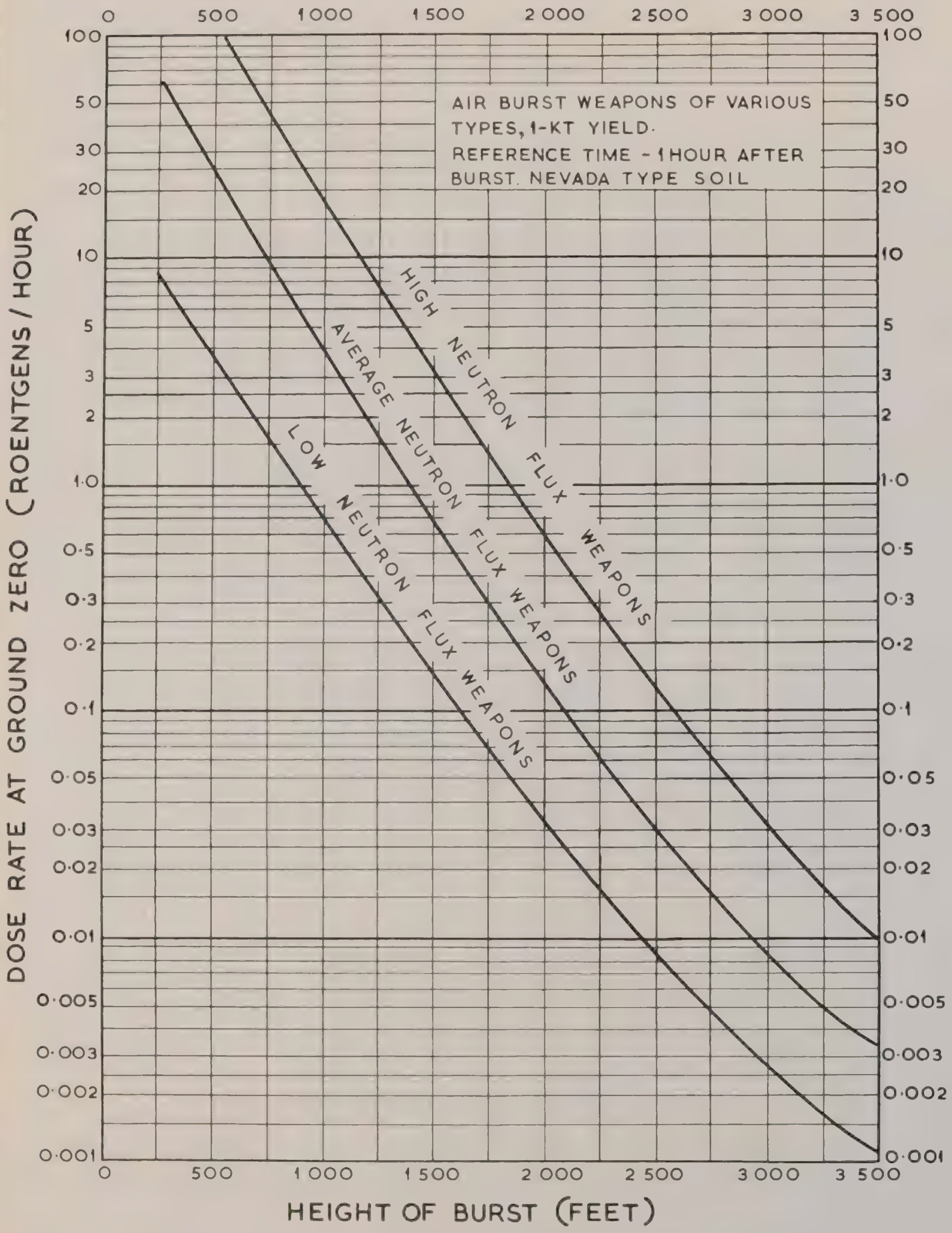


CALCULATION OF THE AGE OF FISSION PRODUCTS



NEUTRON-INDUCED GAMMA ACTIVITY AT GROUND ZERO

3.3. Internal Irradiation

Wherever fallout occurs there is a possibility that radioactive material will enter the body through the digestive tract (due to the consumption of food and water contaminated with fission products), through the lungs (by breathing air containing fallout particles), or through wounds or abrasions. The general biological effects of nuclear radiations from internally deposited sources are the same as those from external sources. It should be noted however, that even a very small quantity of radioactive material, and especially of alpha or beta particle emitters, in the body can produce considerable injury.

The chemical properties of the fallout material which enters the body will determine where it is deposited. Radioactive elements will follow the same absorption process as their naturally occurring isotopes, and elements not usually present in the body will tend to be taken up along with normally ingested elements of similar chemical behaviour. Thus radium, strontium and barium, which are chemically analogous to calcium, will be deposited in the bone.

Unless a radioactive substance is able to pass from the stomach and intestines into the blood stream it is not strictly an internal hazard, and the quantity of the substance absorbed from the gastro-intestinal tract will depend on its solubility in body fluids, particle size, and chemical properties. For example, some fission product materials exist as oxides which are almost insoluble in the body. The oxides of strontium and barium are soluble, so that these elements can readily enter the blood stream and find their way into the bones. Iodine is also present in soluble form, and after entering the blood is concentrated in the thyroid gland. Elements which do not tend to concentrate in a particular part of the system are eleminated fairly rapidly by natural processes.

The uptake of radioactive dust by inhalation depends on the size and chemical nature of the particles. The nose can filter out almost all particles over 10 microns in diameter, and about 95 percent of those exceeding 5 microns. Most of the particles descending in the fallout during the critical period of highest activity, e.g. within 24 hours of the explosion, will be considerably greater than 10 microns in diameter. Consequently, only a small proportion of the fallout particles present in the air will succeed in reaching the lungs. Further, the optimum size for passage from the air space of the lungs to the blood stream is less than 5 microns. The probability of entry into the circulating blood of fission products and other bomb residues present in fallout, as a result of inhalation, is therefore low.

Radioactive material entering thebody through abrasions or wounds has easy access to the blood stream and can rapidly become a serious internal radiation hazard. It is therefore important that where contaimination from fallout is suspected, wounds should be carefully washed and covered.

In addition to the tendency of a particular element to be taken up selectively by a radio-sensitive organ, the main factor in determining the hazard from a given radioactive substance in the body is the total biological dose delivered whilst it is in the body. This dose is governed by the nature and energy of the radiations emitted and the effective half-life of the isotope. The isotopes having the greatest potential internal hazard are those with short radioactive half-lives (i.e. high rate of particle emission) and long biological half-lives. For example, the element iodine has a biological half-life of about 180 days, because it is quickly taken up by the thyroid gland from which it is eliminated slowly. The radioisotope I-131, a fairly common fission product, has a radioactive half-life of only 8 days. It is therefore capable of causing serious damage to the thyroid gland.

In assessing the internal hazard from a radioactive substance it is important to know the maximum permissible total-body-burden (Symbol - q). This is the quantity of radioactive material which can be retained in the body indefinitely without causing injury or ill-health. In giving values for q it is usual to allow a safety factor of 10, i.e. so that a dose of 10q would produce no ill effects. For a dose of 20-30q some chance of injury would be present, and for a dose of (say) 50q, the danger would be considerable. It is convenient to express the maximum permissible total-body-burden in curies (or microucuries) as well as by its weight in grams. The International Commission on Radiological Protection has recommended (Reference (1)) values for q for a large number of radioactive nuclides, and some of these values are quoted in Table 1.

The I.C.R.P. has also recommended values for the Maximum Permissible Concentrations (MPC) for radioactive nuclides in air and water. The MPC value is arrived at in the following way. A person using for very long periods air or water contaminated with a radioactive nuclide at a concentration equal to the MPC will accumulate a quantity of that nuclide in the relevant body-organ such that it will receive an average dose of 0.3 rem per week. The MPC values for some of the more important radioactive elements are given in Table 1.

It should be noted that except in the case of radium direct clinical evidence for the ICRP recommendations does not exist, and in some cases the q values, which are very conservatively chosen, may be considerably in error.

Standards for protection against radiation have also been compiled in the U.S.A. (Reference (2)). The Code gives recommended permissible doses, levels and concentrations, and also covers precautionary procedures and waste disposal.

An attempt to determine the degree of contamination of foodstuffs which could be accepted, and to set out the factors involved in deciding as to the usability of foodstuffs, is made in Reference (3). Permissible doses are discussed, and it is suggested that for specific isotopes a dose of 25 rep during the half-life of the isotope might be acceptable in emergency. For the fission products as a whole a total dose of 25r to the critical part of the gastro-intestinal tract is suggested. It is shown that for times earlier than about six months after the explosion, the gastro-intestinal tract is the critical organ.

The effects of neutron and gamma irradiation upon foodstuffs are reported in Reference (4). A wide variety of packaged and tinned foods were placed at four sites at distances ranging from 1,000 to 1,800 ft. from Ground Zero of Buffalo Round I, (Approximately 20KT). It was observed that it was possible for these foodstuffs to survive in conditions where neutron and gamma irradiation from the atomic explosion predominated over the heat and blast effects. Under the conditions of the experiment, negligible changes in the quality of the food were found, with the exception of deleterious effects on skimmed dried milk.

The activity induced in both the foods and in samples of spectrographically pure chemicals was evaluated, and calculations made to assess the possible radiation hazards from ingestion. It was concluded that even for the nearest site the ingestion hazard was very slight and that phosphorous made the maximum contribution to this hazard. The salvage of foodstuffs from an area near Ground Zero of a nuclear explosion may thus be possible and would not be contra-indicated by any induced radioactivity in the food or by deleterious changes in its quality.

TABLE 1

Maximum Permissible Total-Body-Burden (q) and Maximum Permissible Concentration (MPC) in Air and Water for Continuous Exposure

(Based on Recommendations of the I.C.R.P. 1954)

Radioactive Species	Radiation Emitted	Energy of Radiation Emitted (Mev)	Critical Organ	q Micro-Curies	MPC in Air Microcuries per cc	MPC in Water Microcuries per cc
H3 (HTO or T_2O)	Beta	0.018	Whole body	10^4	10^{-5}	0.2
$C14(CO_2)$	Beta	0.155	Fat	260	10^{-5}	3×10^{-3}
Na24	Beta Gamma	1.39 1.37, 2.75	Whole body	15	2×10^{-6}	8×10^{-3}
P32	Beta	1.701	Bone	10	10^{-7}	2×10^{-4}
S35	Beta	0.168	Skin	300	10^{-6}	5×10^{-3}
Cl36	Beta	0.714	Whole body	230	6×10^{-7}	4×10^{-3}
Fe 55	Gamma (Electron Capture)		Blood	10^3	7×10^{-7}	5×10^{-3}
Fe59	Beta Gamma	0.460 0.257 1.295, 1.10	Blood	13	2×10^{-8}	10^{-4}
Sr90+Y90 (i)Sr90 (ii)Y90	 Beta Beta	 0.61 2.2	Bone	1	2×10^{-10}	8×10^{-7}
I 131	Beta Gamma	0.608, 0.335 and others 0.364, 0.638 and others	Thyroid	0.6	6×10^{-9}	6×10^{-5}
Ra226	Alpha Gamma	4.777 0.186	Bone	0.1	8×10^{-12}	4 x 10^-[illegible]
Pu239 Soluble Insoluble	Alpha Gamma	5.15 0.053, 0.100 and others	 Bone Lungs	 0.04 0.02	 2×10^{-12} 2×10^{-12}	 6×10^{-6}
Any mixture of Alpha Emitters					5×10^{-12}	10^{-7}
Any fission mixture					10^{-9}	10^{-7}

Acceptable emergency beta (or gamma) activities in drinking water, for limited periods of consumption, are given in Table 2, taken from Reference (5), page 535.

TABLE 2

Acceptable Emergency Beta (or Gamma) Activities in Drinking Water

Consumption Period (days)	Activity: Microcuries per cc	Activity: Disintegrations per second per cc
10	9×10^{-2}	3×10^{3}
30	3×10^{-2}	1×10^{3}

The emergency limits for alpha particle emitters, such as uranium and plutonium, in water are appreciably less than those given in Table 2. However, it is expected that only in rare circumstances would these elements represent a contamination hazard in drinking water.

An assessment of the hazards from the inhalation of radioactive dust from a nuclear explosion is given in Reference (6). Numerous pertinent physical and physiological factors are considered, and field and laboratory investigations analysed. It is concluded that there is no conceivable situation in nuclear warfare where, during the first few days after a detonation, one could inhale sufficient radioactive material to induce a serious radiation injury to lungs or intestines without simultaneously being subjected to supralethal doses of external beta and gamma radiations.

References

(1) Recommendations of the International Commission on Radiological Protection. British Journal of Radiology, Supplement No. 6, 1955.

(2) U.S. Code of Federal Regulations No. 10 (10 CFR), Part 20. "Standards for Protection against Radiation".

(3) A.W.R.E. Report No. O-34/56 - "Ingestion of Food Contaminated by Atomic Explosions". (Official Use Only)

(4) A.W.R.E. Report No. T65/57, Operation Buffalo, Biology Group, Part 4B: "The Effects of Neutron and Gamma Irradiation upon Foodstuffs". (Confidential)

(5) Effects of Nuclear Weapons, U.S.A.E.C., 1957.

(6) Operation Teapot, Project 37.3, Civil Effects Test Group, U.S.A.E.C. (Official Use Only)

CHAPTER 4 - EFFECTS ON MATERIALS

Materials which are subjected to very high fluxes of nuclear radiation may undergo permanent changes of structure which are referred to as "radiation damage". Neutrons are by far the most important form of radiation able to cause this type of damage. Gamma rays are also capable of producing changes in materials, but their effect is in general transitory and trivial in comparison with that of neutrons.

A consideration of the order of magnitude of neutron emission from nuclear explosions indicates that fluxes of more than 10^{15} neutrons per sq.cm. are not normally found outside the radius of the fireball (see Figure 10, Chapter 3, Section 3.1). Additionally, except for weapons of small yield, a flux of the order of 10^{11} neutrons per sq.cm. or above will only occur inside the range of severe destruction by the weapon. Table 1 gives a brief summary of the kind of damage suffered by various materials when exposed to integrated neutron fluxes of different intensities. The information in this Table is quoted from Reference (1), which should be consulted if a more detailed treatment of the subject of radiation damage is required. A recently published book dealing with radiation effects in solids is given in Reference (2).

It is thus apparent that in general any materials near enough to a nuclear explosion to sustain radiation damage will have been severaly damaged or destroyed by blast and thermal effects. An exception might arise in the case of a target which is protected from blast and thermal radiation but not effectively shielded against nuclear radiation. This would apply particularly to photographic film and certain electronic equipment, which are more susceptible to radiation damage than ordinary structural materials. The special cases of photographic film and electronic apparatus are dealt with in Part VIII of this manual.

References

(1) Nucleonics, Vol. 14, pp 53-88 (1956) - "How Radiation Affects Materials".

(2) "Radiation Effects in Solids", G.J. Dienes & G.H. Vineyard, (Interscience Publishers, 1957).

TABLE 1

Effects of Radiation on Various Materials

Note. - The levels indicated are approximate, and the changes are in most cases at least 10 percent. The irradiation dose is in epithermal neutrons and expressed as integrated flux.

Neutrons per sq. cm.	Material	Property Change
10^{14}	Germanium Transistor*	Loss of amplification
	Glass	Colouring
10^{15}	Polytetrafluorethylene	Loss of tensile strength
	Polymethacrylate and cellulosics	Loss of tensile strength
	Water and least stable organic liquids	Gassing
10^{16}	Natural and Butyl rubber	Loss of elasticity
10^{17}	Organic liquids	Gassing of most stable ones
	Polyethylene	Loss of tensile strength
	Butyl Rubber	Large changes, softening
10^{18} to 10^{19}	Phenolic polymer	Loss of tensile strength
	Natural rubber	Large change, hardening
	Hydrocarbon oils	Increase in viscosity
	Metals	Increase in yield strength
	Carbon Steel	Reduction of notch-impact strength
	Polystyrene	Loss of tensile strength
10^{20}	Ceramics	Reduced thermal conductivity, density, crystallinity
	All plastics	Unusable as structural materials
	Carbon steels	Severe loss of ductility, yield strength doubled
	Stainless steels	Yield strength tripled
10^{21}	Aluminium alloys	Ductility reduced but not greatly impaired
	Stainless steels	Ductility reduced but not greatly impaired

*See also Part VIII of this Manual.

CHAPTER 5 - SHIELDING FROM INITIAL RADIATORS

5.1. Gamma Radiation

5.1.1. Basic principles - A description of the nature and origin of the initial gamma radiation from a nuclear weapon is given in Chapter 5 of Reference (1). An unclassified account will be found in Chapter 8 of Reference (2). In considering shielding problems, it is important to note that this gamma radiation has complicated distributions of both energy and direction and that these distributions vary with distance from the explosion and height above the earth's surface. Because of this, it is not possible in practical shielding problems to base calculations on the actual physical nature of the incident radiation.

The parameters which control the efficiency of shielding are the mass of material between the source of radiation and the target, the energy distribution of the gamma rays at the target, the angle of the incident radiation, and the geometry of the shielding. Observations made at weapon tests have enabled the calculation of attenuation factors which combine these controlling parameters. The solutions to practical shielding problems are normally obtained by the use of a simplified model and the application of appropriate attenuation factors.

References

(1) A.W.R.E. Manual on the Effects of Atomic Weapons, 1955 (Secret/Atomic/U.K. Eyes Only)

(2) Effects of Nuclear Weapons, U.S.A.E.C., 1957.

5.1.2 The interaction of gamma rays with matter

There are three types of interaction between gamma rays and matter which lead to the scattering or absorption of the gamma photons and so are of importance in considering shielding. They are:-

(a) the photoelectric effect;

(b) the Compton effect;

(c) pair production.

A brief description follows for the convenience of those not requiring a detailed treatment, such as may be found in References (1) and (2).

(a) Photoelectric effect - In this type of interaction a gamma photon with energy greater than the binding energy of an orbital electron transfers all its energy to the electron, which is then ejected with considerable energy from the atom. After such a photoelectric interaction, the photon ceases to exist. The probability of a photon being absorbed in this manner, per atom, is proportional to the fifth power of the atomic number of the material through which the gamma radiation is passing, but it decreases rapidly with increasing photon energy. Even in the case of lead this photoelectric effect is relatively unimportant above 1 Mev, and for light elements, above a few Kev.

(b) Compton effect - Here a gamma photon exhibits particle properties, and its encounter with an electron results in an elastic or 'billiard ball' collision. The photon transfers some of its energy to the electron and at the same time is deflected from its original path. The energy loss and the angle of deflection are closely related. The magnitude of this effect per atom is proportional to the number of electrons in the atom on the shielding element, and hence to its atomic number, but the effect decreases with increasing photon energy. Unlike the case of the photoelectric effect, the photon does not disappear completely after a Compton interaction, but continues in a changed direction with reduced energy and an energetic Compton electron is released.

(c) Pair production - A photon with energy greater than about 1.02 Mev may, when it passes near to an atomic nucleas, be annihilated with the production of a pair of particles, one a negative electron and one a positron. Any energy in excess of 1.02 Mev, the energy required to form the pair of particles, appears as kinetic energy of the pair. This type of interaction results in the complete disappearance of the photon. Pair production cannot occur with photon energies less than 1.02 Mev, and thereafter the probability of the effect increases with both photon energy and atomic number.

In considering the three types of interaction described above, it is seen that in all cases the magnitude per atom increases with increasing atomic number (or atomic weight) of the materials through which the gamma rays pass. Each effect too, is accompanied by either the complete removal of photons or a decrease in their energy. The net result is some attenuation of the gamma ray intensity or dose rate. Since there is an approximate parallelism between atomic weight and density, the number of atoms per unit volume does not vary greatly from one substance to another. Hence, a given volume (or thickness) of a material containing elements of high atomic weight ('heavy elements') will be more effective as a gamma shield than the same volume (or thickness) of one consisting only of elements of low atomic weight ("light elements").

Another important point is that the probabilities of the Compton and photo-electric effects (per atom) both decrease with increasing energy of the gamma photon. Combination of these various attenuating effects, two of which decrease whereas one (pair production) increases, with increasing photon energy, means that at some energy (in excess of 1.02 Mev) the absorption of gamma radiation by a particular material should be a minimum.

References

(1) The Quantum Theory of Radiation, W. Heitler, 1953.

(2) U.S. Atomic Energy Commission Report NYO 3075, by Goldstein and Wilkins.

5.1.3 Gamma radiation attenuation laws

Photons which are involved in photoelectric or pair production interactions are completely lost from the gamma ray beam. If it is assumed that photons involved in Compton encounters are also lost from the beam, the attenuation law for a parallel beam will be as follows:-

$$I = I_o e^{-\mu} \qquad (5.1.1.)$$

Where I is the intensity behind the shield,

I_o is the intensity at the same point in the absence of the shield

x is the thickness of the shield, and

μ is the absorption coefficient for the material of the shield for the gamma rays under consideration.

The total absorption coefficient μ is made up of separate coefficients, μ_{pe}, μ_c, μ_{pp}, for the three effects described above. Figure 1 gives the values of these coefficients for lead, a typical heavy element with a large absorption coefficient, and Figure 2 the values for air, a mixture of light elements withaa small absorption coefficient, Reference (1).

In the discussion so far, we have used the simplifying assumption that photons involved in Compton collisions are lost from the beam. In fact however, many photons which have been deflected and degraded in energy one or more times will arrive behind the shield and will consequently increase the intensity to a value greater than that given by Equation 5.1.1. This, the usual practical situation, is sometimes referred to as "Bad Geometry". It will be seen that even if the incident beam were homogeneous and parallel, the beam emerging behind the shield would not be so. When the radiation from a nuclear weapon is considered, even the incident beam possesses a complicated spectrum of energies and directions. In such circumstances direct calculation of shielding based on numbers of photons, their energies and directions becomes too tedious. It should be noted that the effects against which shields are established are all dependent on the energy actually absorbed within the individual or object being protected, and consequently it would be necessary to compute both the overall reduction in flux of the photons, and the degradation of their energies in order to determine the shielding effects. As the reduction in direct radiation may be offset by scattering from other parts of the shield or from other objects, and also the mean energy of the radiation may be reduced in such a way as to increase the amount actually absorbed in the object to be protected, the overall analysis is likely to be tedious. In practice the best solution is to make observations at weapon trials of the reduction of dose or dose rate (ion pairs per cc per second) in the object or simulated object behind the various shields, and then to determine an "equivalent homogeneous radiation" by one of the published approximate methods of calculation. See References (2), (3) and (4) for details.

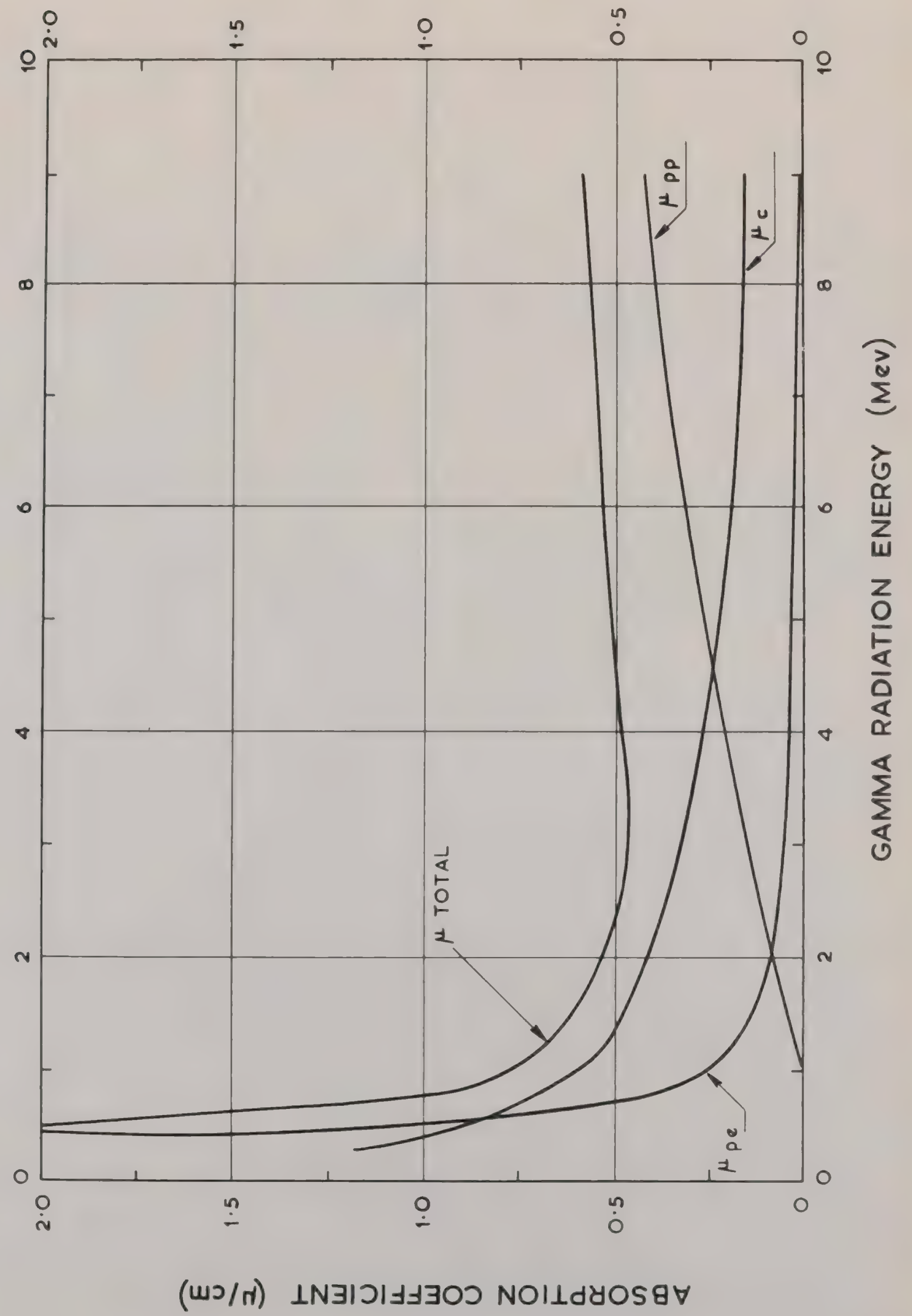
References

(1) The Effects of Nuclear Weapons, U.S.A.E.C., 1957, p. 376.

(2) Cave, Corner and Liston, Proc.Roy.Soc. Vol. A.204, p.223, 1950 "Perpendicular Incidence on a Plane Slab"

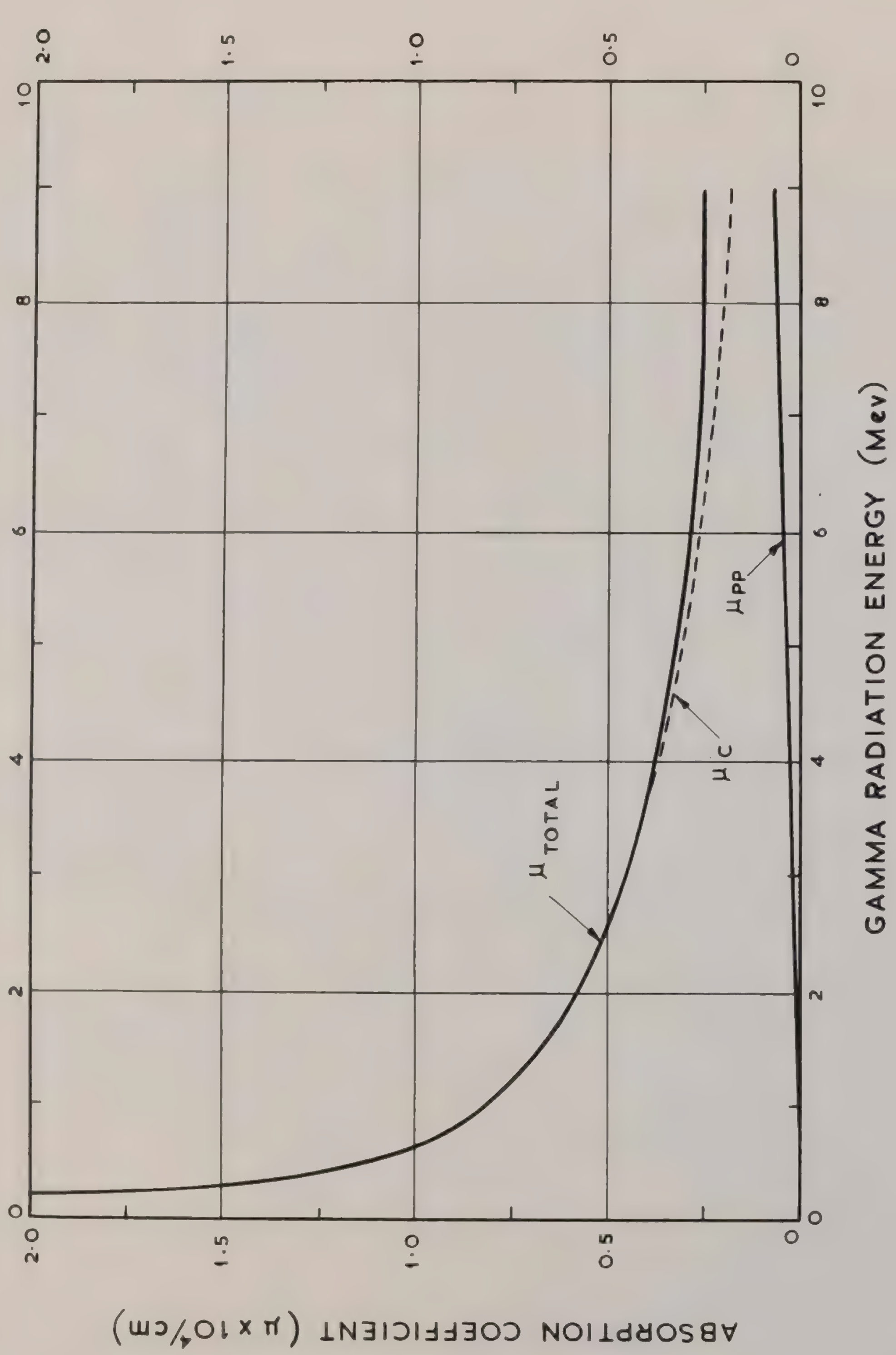
(3) Ministry of Supply, H.E.R. Report No. H13/51 (Restricted) "Tables for the Solution of Gamma Ray Shielding Problems"

(4) A.W.R.E. Report No. T53/54 (Secret) - "Penetration of Concrete Slabs by Gamma Radiation".



ABSORPTION COEFFICIENT OF LEAD FOR GAMMA RADIATIONS

UNCLASSIFIED



ABSORPTION COEFFICIENT OF AIR FOR
GAMMA RADIATIONS

UNCLASSIFIED

5.1.4. Attenuation data for light elements

"Light elements" in this connection are elements with an atomic number less than about 30, that is, corresponding to atomic weights up to about 65 (Zinc). For such elements the preponderant mechanism of attenuation is the Compton effect.

The protective qualities of a shield can be defined by the "attenuation factor", which is the ratio of the dose immediately behind the shield to the dose which would be at that point in the absence of the shield. Methods of computing attenuation factors for simplified conditions have been described in References (1) and (2). Figure 1 is based on those methods applied to radiation beams perpendicular to a concrete shield of density 144 lb./cu.ft. (2.3 gm/cc). Equivalent thicknesses of other light element materials are inversely proportional to the density of the material. A list of densities of a number of common materials is given in Table 1.

Measurements of dose reduction by concrete shields were made at British trials of weapons in the kiloton range (Operation Totem), References (3) and (4). The results indicated a photon energy of 1 Mev used in the "modified upper limit" method of calculation (Reference (2)) to be satisfactory. For thin shields (less than about six inches of concrete) close enough to the weapon for the free air dose to be greater than 200 r, an energy of about 0.5 Mev is more realistic. Figure 1 is calculated on the "modified upper limit" formulae and therefore may be used without further calculation. More recent results from Operation Buffalo (Reference (5)) differ from those obtained at Totem, and show that the design of the weapon is the dominant factor. The penetration of gamma-rays through concrete slabs at Buffalo appeared to be consistent with exponential attenuation with a half-thickness of concrete corresponding to 51 $lb./ft.^2$. Thus the radiation appeared to be considerably harder than at Totem where the half-thickness correspond to 20-29 $lb./ft.^2$.

Figure 2, taken from Reference (6), gives attentuation factors for various materials as a function of shield thickness.

No experimental results are available for megaton weapons, but because of the probable increase in the amount of $(n.\gamma)$ radiation from nitrogen in the air it is expected that a higher energy would have to be used. Approximate calculations based on U.S. data for "free air" doses suggest about 5 Mev.

It should be noted that the absorption of neutrons in light elements is accompanied by the production of gamma radiation, of which account must be taken. References (7) and (8) give details of this.

References

(1) Cave, Corner & Liston, Proc.Roy.Soc. Vol. A.204, p.223, 1950 "Perpendicular Incidence on a Plane Slab".

(2) Ministry of Supply, H.E.R. Report No. H13/51 (Restricted) "Tables for the Solution of Gamma Ray Shielding Problems".

(3) A.W.R.E. Report No. T53/54 (Secret) - "Penetration of Concrete Slabs by Gamma Radiation".

(4) A.W.R.E. Report No. T20/54 (Secret) - "The Penetration of the Gamma Flash into Anderson Shelters and Concrete Cubicles".

(5) A.W.R.E. Report No. T42/57, Operation Buffalo. "Attenuation and Scattering of Initial Nuclear Radiations".
(Secret/Atomic/U.K. Eyes Only)

(6) Effects of Nuclear Weapons, U.S.A.E.C, 1957, p.357.

(7) Nucleonics, Vol. 13 (No.5) pp.50-51. Shielding Constants. Gamma Rays from Thermal Neutron Capture.

(8) Nucleonics, Vol. 15 (No.4) pp.84-85. Induced Radiation. Radiation from Neutron Activated Slabs and Cylinders.

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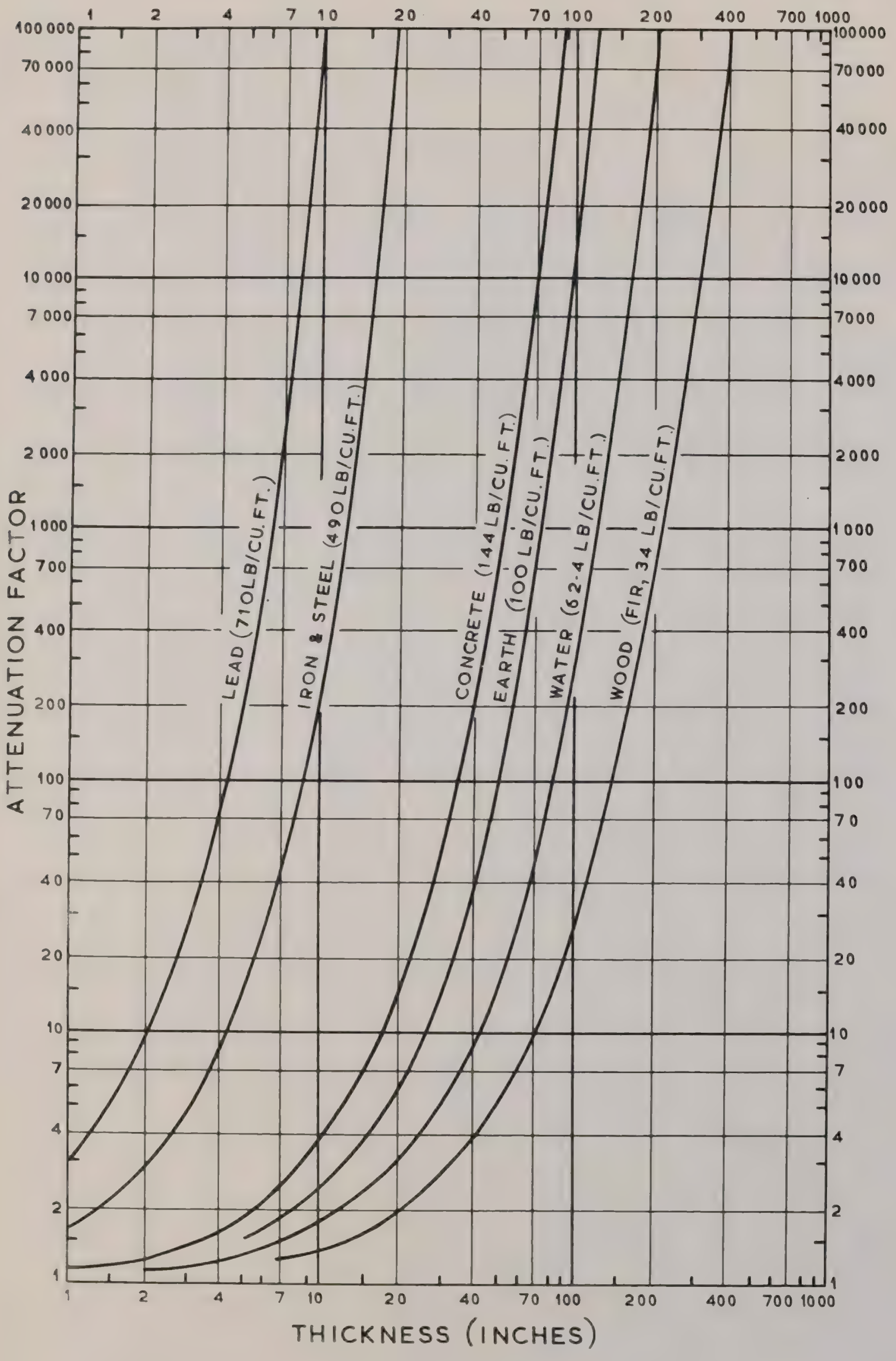

ATTENUATION OF INITIAL GAMMA RADIATION

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5.1.6 Shielding by some common structures

The shielding data for parallel beams of radiation falling on simple shields are only of limited value in dealing with the protection afforded by actual structures. A few results are available from trials of weapons in the kiloton range and these, together with the results of some theoretical studies, are given here:-

(i) Concrete cubicles

At Operation Hurricane (Reference (1)) a number of concrete cubicles were built and gamma ray attenuation measurements were made by means of film badges placed across each cubicle, all at a height of 6 ft. The concrete had a density of about 133 lb./cu.ft. and the cubicles had sides 12 ft. long and 12 ft. high. The following results were obtained:-

Wall thickness (inches)	No. of badges	Attenuation Factor	
		Average	Range
$6\frac{3}{4}$	4	0.16	0.15 - 0.20
$9\frac{3}{4}$	3	0.096	0.082 - 0.12
12	4	0.064	0.057 - 0.079

Further observations on the penetration of concrete slabs by initial gamma radiation were made at Operations Totem and Buffalo (see also Section 5.1.5 of this chapter). It would appear from the evidence available (Reference (2)) that the gamma radiation from Buffalo Round 1 was substantially harder than that from Totem Round 1. The Buffalo half-thickness was about $4\frac{3}{4}$ inches of concrete (or 51 lb./ft.^{2}) compared with the Totem half-thickness of about $1\frac{3}{4}$-$2\frac{1}{2}$ inches of concrete (or 20-29 lb./ft.^{2}). The American data summarized in Reference (5) are more nearly in accord with the Buffalo results.

(ii) Anderson Shelters

A limited amount of information on these shelters was obtained at Operation Hurricane (Reference (1)). Owing to the irregular shape of this type of shelter, and the impossibility of maintaining a constant soil coverage, the results vary from one shelter to another. On average however, it was found that the attenuation factor in that part of the shelter which was above ground was about 0.03, while for the underground part of the shelter the factor was about 0.02. The penetration of Anderson shelters by initial gamma radiation was also studied at Operation Buffalo (Reference (2)) but the results showed considerable variation. A mean attenuation factor of about 0.05 was obtained.

(iii) Trenches

The protection afforded by trenches has been studied by A.O.R.G. (Reference (3)), and information obtained from tests with slit trenches and circular holes at Operation Totem, has been reported (Reference (4)).

The protective value of a trench depends on several factors, such as depth, orientation, nature of soil, amount and type of cover, angle of elevation to the burst, and the position at which the dose is measured. Some average figures for trenches 6' x 2' x 4'6" deep have been taken from the A.O.R.G. Report (Reference (3)) and are shown in Figure 1. Some values for gamma attenuation factors for circular pits at Operation Totem (Reference (4)) are given in Table 1. These pits were 6 ft. deep and 4 ft. in diameter, and those designated 'closed' were completely covered by an 18 inch thick layer of sandbags. The dose measurements were made with film badges mounted at the

stated heights on the centre line of each hole.

TABLE 1

Gamma Attenuation Factors for Circular Pits at Operation Totem

Depth below surface (inches)	Distance from Ground Zero and Exterior Dose							
	1710 ft. (11000r)		2720 ft. (950r)		3760 ft. (110r)		6010 ft. (4.7r)	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed
0	1.0	96	1.0	63	1.0	78	1.0	36
6	2.1	100	3.7	56	2.8	55	3.4	39
12	3.8	105	7.3	53	5.2	52	6.5	47
24	12	120	16	79	13	100	15	94
36	21	150	29	155	24	165	24	105
48	38	190	45	250	39	240	34	120
60	58	310	63	320	52	330	48	140
72	92	610	86	380	61	380	64	170

Information on initial gamma attenuation factors, from an American source (Reference (5)), is listed in Table 2.

TABLE 2

Attenuation Factors for Initial Gamma Radiation

Geometry	Attenuation Factor		
Foxholes[a]	0.05	-	0.10
Underground - 3 ft.	.04	-	.05
Frame House			.9
Basement	.05	-	.5
Multistory building			
Upper			.9
Lower	.3	-	.6
Blockhouse walls			
9 inches			.1
12 inches	.05	-	.09
24 inches	.01	-	.03
Shelter, partly above ground level			
with earth cover - 2 ft.	.02	-	.04
with earth cover - 3 ft.	.01	-	.02
Tanks: M-24, M-41; Tank Recov. Veh. M-51, M-74	.1	-	.2
Tanks: M-26, M-47, M-48, T-43E1: Eng. Armd. Vehicles T-39E2	.05	-	.15
$\frac{1}{4}$ ton Truck			1.0
$\frac{3}{4}$ ton Truck			1.0
$2\frac{1}{2}$ ton Truck			1.0
Armd. Inf. Veh. M-59, M-75 and SP Twin 40 mm Gun M-42	.2	-	.5
SP 105 mm Howitzer M37	.4	-	.6
Multiple Cal. .50 m.g. Motor Carriage M-16	.8	-	1.0
LVT (Landing Vehicle Tracked)	.5	-	.9
Battleships and Large Carriers[b]			
15% of Crew			1.0
25% of Crew			.2
10% of Crew			.05
50% of Crew	.0005	-	.005
Cruisers and Carriers[b]			
10% of Crew			1.0
20% of Crew			.5
30% of Crew	.1	-	.3
40% of Crew	.005	-	.1
Destroyers, Transports and Escort Carriers[b]			
10% of Crew			1.0
20% of Crew			.7
30% of Crew			.4
40% of Crew	.1	-	.4

a No line-of-sight radiation received
b Crew at General Quarters

References

(1) A.W.R.E. Report No. T20/54

(2) A.W.R.E. Report No. T42/57

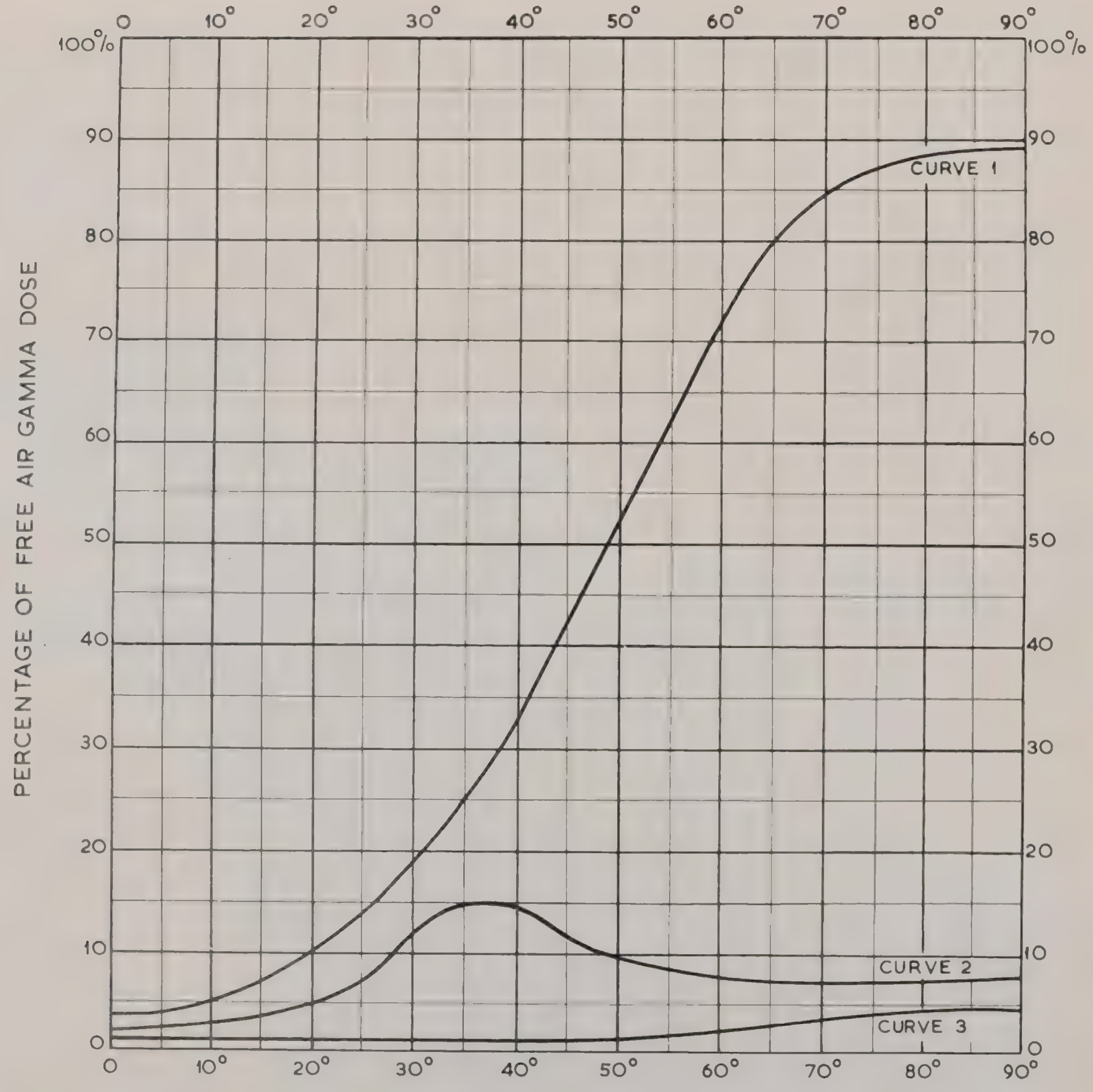
(3) Army Operational Research Group, Report No. 12/55

(4) A.W.R.E. Report No. T6/56

(5) Capabilities of Atomic Weapons. A.F.S.W.P. TM23-200(1957)
(Confidential/Discreet)

SECRET
U.K EYES ONLY

CURVE 1 OPEN TRENCHES
CURVE 2 TRENCHES WITH 18" RAISED EARTH COVER
CURVE 3 TRENCHES WITH 18" FLUSH EARTH COVER



SHIELDING VALUES FOR TRENCHES
AGAINST GAMMA RADIATION

5.2 Neutrons

5.2.1 Basic principles

Essentially all the neutrons accompanying a nuclear explosion are released either in the fission or fusion process. All of the neutrons from the latter source and over 99% of the fission neutrons are produced almost immediately, probably within less than a millionth of a second of the initiation of the explosion. These are referred to as the 'prompt' neutrons.

In addition, somewhat less than 1% of the fission neutrons, called the 'delayed' neutrons, are emitted subsequently. Since the majority of these 'delayed' neutrons are emitted within the first minute, however, they constitute part of the initial nuclear radiation. Some neutrons are also produced by the action of gamma rays of high energy on the nuclear bomb materials, but these make a very minor contribution and so can be ignored.

Neutrons bear no charge and so do not directly ionise the medium through which they are moving. Their mass is comparable to that of the lighter elements, and they may undergo strong interactions with nuclei. Because of these two properties, neutrons may cause ionisation indirectly (a) by elastic collisions, and (b) by capture by nuclei.

(a) Elastic collisions - In an elastic collision the neutron and the nucleus with which it collides may be considered to behave as rigid spheres. If the neutron is moving so fast compared with thermal velocities that the nucleus with which it collides may be treated as being at rest, the energy of this nucleus after the collision will be between 0 and E_{max}, where:

$$E_{max} = \frac{4A}{(A+1)^2} E \qquad (5.2.1)$$

E = The energy of the neutron before collision

A = The atomic weight of the nucleus.

For light elements the scattering is usually isotropic, and in this case the average energy of the nucleus will be $\frac{1}{2} E_{max}$. Thus, in an elastic collision a neutron with kinetic energy greater than about 1 Kev can impart enough energy to a light nucleus to enable that nucleus to ionise the material through which it moves. The density of ionisation caused by such a nucleus is very great and therefore its range will be very much shorter than that of an electron of the same energy (approximately $\frac{1}{100}$ for the H nucleus).

(b) Neutron capture - Any interaction between neutrons and nuclei other than elastic scattering is considered to proceed through the formation of a 'compound nucleus' made up of the incident neutron and the nucleus it has struck. This compound nucleus is invariably formed in an excited state and it may lose this excitation energy in a variety of ways, with corresponding end products.

(i) Inelastic scattering - The compound nucleus emits a neutron of energy less than that of the incident neutron, and a gamma-ray. This process can only occur if the energy of the incident neutron exceeds that of the first gamma emitting state of the target nucleus. This threshold energy effect is also shown by the capture processes involving charged particle emission. The process of inelastic scattering is denoted by $(n, n\gamma)$, where the symbol before the comma denotes the ingoing particle, and the symbols after the comma represent the outgoing particles.

(ii) Radiative capture (n,γ) - In this case a gamma-ray only is emitted after the neutron has been captured. This is the most common reaction between nuclei and thermal neutrons. Highly energetic gamma rays can be produced. The resulting nucleus, of increased atomic weight, may be unstable.

(iii) Charged particle emission - (n, q) - The particle emitted is usually either a proton (n, p) or an alpha particle (n,α); more rarely other light nuclei may be emitted. There are two important cases where charged particle emission may follow the absorption of a thermal neutron, namely N^{14} (n, p) and B^{10} (n,α). These charged particles will have a short range and be densely ionising. It should be noted that the nucleus remaining after (n,γ) or (n, q) may be radioactive.

The probability of occurrence and relative importance of these processes vary considerably with the energy of the neutrons and the composition of the material through which they are moving. In dealing with the effect of neutrons from a nuclear weapon on any target it is therefore necessary to know something of the neutron energy spectrum, that is the distribution of energy values among the neutrons, as well as of the composition of the target. Since the prompt neutron energies are fairly well known, it should be possible, in principle, to calculate the energy spectrum of the neutrons after penetrating the bomb materials. However, since these materials are not completely dispersed when the neutrons are emitted, the neutron spectrum depends on the detailed geometry of the bomb components at an extremely complex stage of the explosion. Variations in bomb design may therefore give rise to wide variations in the energy distribution and intensity of the neutron flux. Because of this, a theoretical solution is virtually impossible and one must resort to experiments.

It is, however, very difficult to measure the neutron spectrum from a nuclear explosion at distances of interest. The method at present adopted is to estimate the number of neutrons with energies above certain values by measuring the activity induced in suitably chosen targets which can be activated only by neutrons having energies above these values. The interpretation of the results obtained may give rise to difficulties.

Elastic and inelastic scattering eventually reduce the energy of all neutrone that are not absorbed to a level where they are in thermal equilibrium with the surrounding medium (thermal neutrons); at normal temperatures this energy is about 0.025 ev. At energies of this order the cross section for the (n,γ) process in many elements is large, and when the product nucleus is radioactive and has a suitable half-life (of the order of a few hours), targets of such elements provide a convenient method of estimating the number of 'thermalised' and 'nearly thermalised' neutrons reaching the target.

A detailed account of the mechanisms and problems of neutron shielding is given in Chapters 3 and 4 of Reference (1).

References

(1) "Radiation Shielding". B.T. Price, C.C. Horton, and K.T. Spinney. (Pergamon Press, 1957)

5.2.2 Yield and Energy Spectrum

The neutron flux in various energy bands, and the neutron dose, have been measured over a range of distances from nuclear weapons at a number of trials. Up to the present, British measurements of the neutron spectrum have been limited to assessing the numbers of neutrons reaching the target in two energy groups which are referred to as fast and slow neutrons. The number of fast neutrons is deduced from the activation of S^{32} by the (n,p) reaction which is considered to have a threshold at 2.5 Mev and yields P^{32}, a beta emitter with a half-life of 14.3 days. The number of slow neutrons, i.e. neutrons with energy below about 0.2 ev, is deduced from the activity induced in target materials in which an (n,γ) reaction produces a radioactive nucleus.

In order to estimate the number of neutrons with energies between 0.2 ev and 2.5 Mev the Americans have used detectors of U^{238} (which has a threshold for fission with neutrons at 1.5 Mev), Np^{237}, (fission threshold 0.7 Mev), and Pu^{239} in a boron shield, (fission threshold 100 ev). The results show that at distances greater than 1,500 feet from the explosion the proportion of neutrons in each of the energy bands is approximately the same for all distances and for all weapons, although the total flux decreases rapidly with increasing distance. This is illustrated in Figure 1 which is derived from data given for a 20 KT weapon in References (1) and (2). It gives the number of neutrons/cm^2 in each energy group reaching the groun as a function of distance from the explosion.

However, the external neutron yield per kiloton varies considerably with the design of the weapon. The extent of this variation in American weapons is shown in Figures 8 and 9, Chapter 3, Section 3.1, which show the upper and lower limits of neutron dose per kiloton as a function of distance and are taken from Reference (3). A similar spread is shown in the values obtained on British tests of weapons in the kiloton range (Reference (4)). According to Reference (5) the values given in Figure 1 apply to a low neutron yield weapon.

References

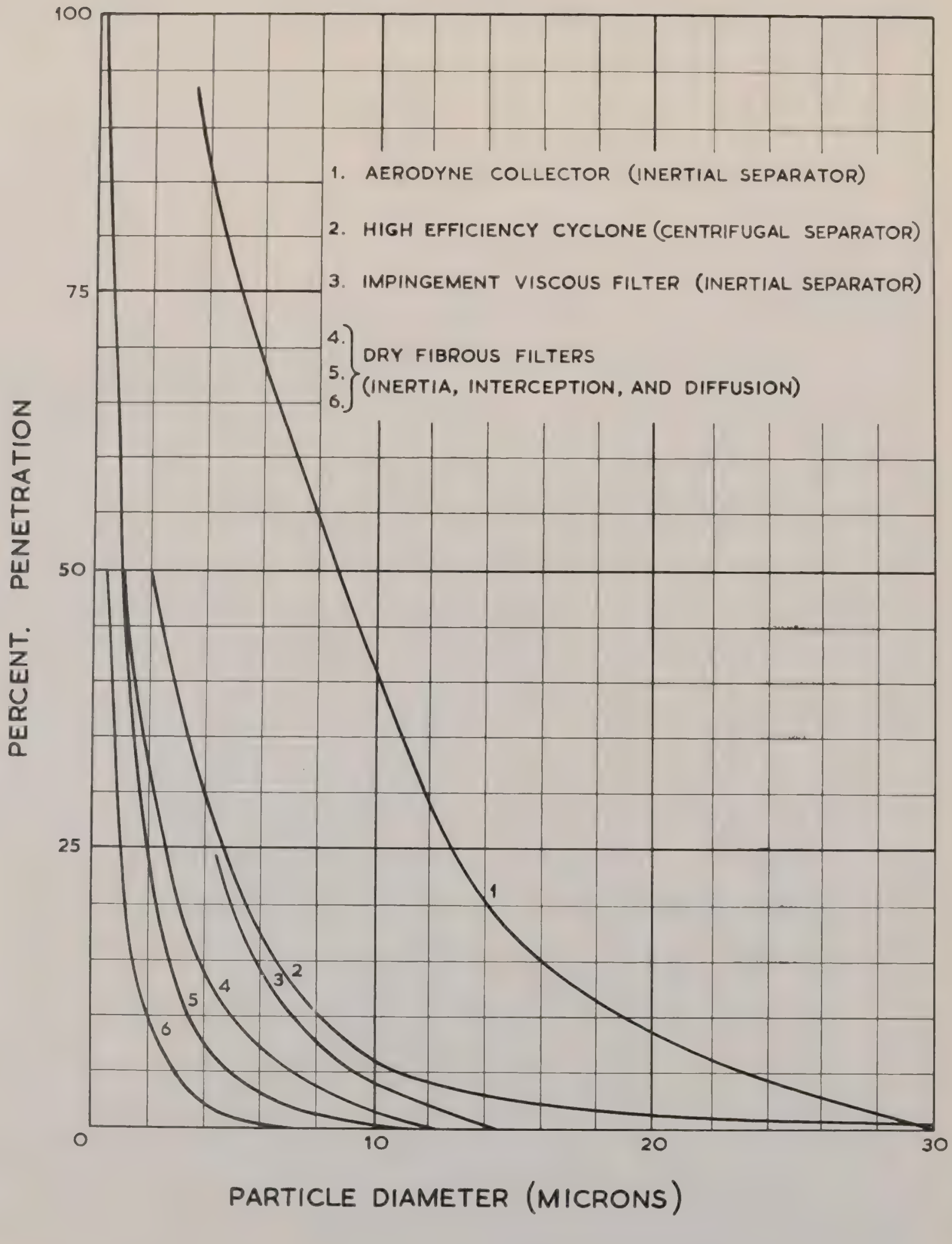
(1) The Effects of Atomic Weapons, page 243, U.S.A.E.C., 1950.

(2) The Effects of Nuclear Weapons, page 385, U.S.A.E.C., 1957.

(3) Capabilities of Atomic Weapons, A.F.S.W.P. TM.23-200 (1955) (Confidential/Discreet)

(4) A.W.R.E. Report No. T59/57.

(5) A.W.R.E. Report No. E5/54.



FILTER EFFICIENCIES

7.7.3. Filters

The problem of cleaning contaminated air supplies to buildings etc. may be overcome by the installation of an adequate filtration system to the air intake. Factors to be considered in designing a filtration system include the size-distribution of the cloud to be filtered, the air requirements, the available space, the pressure-drop limits, and the degree of filtration considered to be adequate. The latter includes an estimate, at present somewhat uncertain, of the relationship between particle size and activity.

Although a large number of filtration systems are available, the basic principles underlying their operation are few, and comprise centrifugal and inertial forces, interception, diffusion and electrostatic forces. A detailed discussion of these principles is beyond the scope of this manual, but their application is illustrated by the curves in Figure 1, which give performance data for some typical filters.

These curves show the penetration/particle size characteristics of the various filters. As a general routine however, it is convenient to compare filters by reference to some standard test. In the case of fibrous filters, the methylene blue test described in British Standard Specification 2831:1957 is a convenient method. Essentially it consists of determining the mass penetration of a methylene blue dye cloud by comparing the density of stains corresponding to known volumes of the filtered and unfiltered cloud. The mass median diameter of particles in the methylene blue cloud is about 0.5 microns, and constitutes a severe test for filters.

The problem of filtering particulate matter arising from nuclear explosions may be considered in terms of the two hazards (cloud contamination and surface contamination) discussed in Sections 7.6.1 and 7.6.2 respectively.

Aircraft will require a filter of high efficiency against rather small particles, since this filter may have to deal with the cloud of condensed-fission products alone. The curves in Figure 1 indicate that a dry fibrous filter will be needed, the actual details being subject to practical design considerations. As an illustration, a comparison between the methylene blue penetration and the estimated fission product cloud penetration for three types of fibrous filter are given below.

Filter 1 - Methylene blue penetration 50%

Mass penetration of fission product cloud, 6.0%

Particle diameter (microns),	0.5,	1.0,	2.0,	3.0
Percent penetration	50.0,	25.0,	10.0,	4.0

Filter 2 - Methylene blue penetration 25%

Mass penetration of fission product cloud 2.0%

Particle diameter (microns)	0.5,	1.0,	2.0
Percent penetration	25.0,	10.0,	1.0

Filter 3 - Methylene blue penetration 0.05%

Mass penetration of fission product cloud, 0.001%

Particle diameter (microns)	0.5,	1.0
Percent penetration	0.05,	0.001

Filters for dealing with fallout will probably be satisfactory if they prevent the penetration of particles greater than about 10 microns diameter, since the evidence available indicates that the greater part of the material will consist of particles larger than 10 microns. It is not however, certain whether the activity will be reduced in proportion to the mass filtered. Examination of Figure 1 shows that practically all the filters would remove a substantial part of the fallout, and that there is considerable scope for the design of systems capable of dealing with this hazard. The concentration of activity by the filter may lead to a radiation hazard, and the siting of the filter and the provision of protection for plant room operators will have to be considered.

In a study of filters suitable for use against fallout, Thomas (Reference (1)), concludes that impingement type filters (e.g. oil-coated glass fibre, oiled metal gauze, etc.) could not be relied upon to provide adequate filtration, but that the overall performance of the fabric bag and the thin dry fibrous air conditioning types of filter should be satisfactory, provided the face velocity is limited to a maximum of 70 feet/minute. It is suggested by Thomas that a maximum methylene blue penetration of 90% and a maximum face velocity of 70 feet/minute be specified for fibrous filters against fallout.

For further general information on the subject of particulate clouds and dust, including their filtration, the reader is referred to the recent book by Green and Lane, Reference (2).

References

(1) Thomas, D. H. "Filters for Fallout", Porton Technical Paper No. 595, April, 1957. (Confidential)

(2) Green, H. L. and Lane, W. R. - "Particulate Clouds, Dusts, Smokes and Mists", (Spon, 1957)

7.7.2. Protective clothing

Radioactive dust may be encountered during a period of fallout, or later, in association with contaminated ground. The radiation from the airborne dust will always be small, and in the latter instance negligible in comparison with that from the ground. Wearable clothing has no effect on the gamma intensity, although it may somewhat reduce the beta intensity. Although clothing will therefore give little direct protection, it is of value in acting as a barrier to dust contamination which can be removed after the period of exposure and destroyed or decontaminated. By this means the need to decontaminate exposed parts of the body and the ordinary clothing can be avoided.

Requirements

These may be considered under the following headings:-

(1) Resistance to penetration by dust

(2) Low dust retention

(3) Ease of decontamination

(4) Good comfort and wearability

(5) Low cost and avoidance of use of scarce materials

(6) Rain or showerproofness

(7) Durability.

The individual requirements for protective clothing are inter-related, and the best practical garments are those which afford the best compromise. The greatest resistance to penetration will obviously be afforded by impermeable materials whose smooth surfaces also retain very little dust, and are usually (but not necessarily) relatively easy to decontaminate; such materials may cause severe thermal stress and be wearable only for short periods, particularly when heavy work is being performed. Permeable fabrics, if made smooth and fairly close-woven, can give good protection, and are much cooler, but would probably be inadequate against wet fallout.

Materials

Information regarding the suitability of different materials for use in protective garmetnts, is scanty. In the impermeable class, P.V.C. and particularly rubber, are difficult to decontaminate; polythene and polystryrene are the best of the commonly available materials. Permeable fabrics vary considerably, both in the degree of take-up and ease of decontamination. Terylene and nylon fabrics are better in both respects than those made from natural fibres. Wool retains more dust than cotton, but is more easily decontaminated. Improved methods of decontamination may be more effective for one material than for another, and thus may change the order of preference. However, it is most likely that other factors than dust take-up and ease of decontamination will continue to determine the materials used.

Three distinct conditions can be envisaged which would have a bearing on the protective clothing requirement:-

(1) Exposure to wet fallout

(2) Exposure to dry fallout

(3) Heavy or moderate work under dust-raising conditions in a contaminated area.

(1) and (2) may occur during the evacuation of an area after a nuclear explosion. In view of the likely incidence of rain, clothing for this purpose could be impermeable, but there would be no need for durability, and a light plastic garment would be adequate. Decontamination would probably not be required, in which case P.V.C. would suffice. (3) would normally be after fallout had occurred, and the hazard would therefore be less under wet conditions, which would keep the dust settled. Fairly heavy duty permeable fabric, showerproofed would provide the best compromise between resistance to penetration and comfort. The clothing designed for use at British atomic weapon tests, was made of this type of material.

Design of Clothing

The clothing must cover the whole body. Essentially, this calls for a one or two-piece suit with dust closure at the wrists and ankles, and a hood covering the head. When necessary, the face will be covered with a full-face respirator or half-mask and eye-shield. Difficulty was experienced in decontaminating the rubber boots used at 'Hurricane' and other Operations, and the problem of footwear and over-boots is still under investigation.

An account of a clothing trial made during Operation 'Buffalo' is given in Reference (1), Various types of military and protective clothing were tested in a fallout area, and the degree of protection afforded and the extent to which the clothing became contaminated were investigated. Under the conditions of test all the types of clothing tested gave adequate protection. provided the whole body was covered. Ease of decontamination was dependent on the nature and weight of the fabric, and in this respect the A.W.R.E. Combination suit and khaki drill were superior to the gaberdine Combat suit and serge Battle Dress.

Respirators

Respirators are not radiologically necessary for at least the first month after fallout. The question of the biological necessity for wearing respirators in old fallout fields is still under investigation. The wearing of respirators depends on an accurate assessment of the prevailing inhalation and ingestion hazard in relation to the tolerance dose. Complete protection is given by any of the civilian or Servicx type respirators, as well as by the approved commercial dust respirators.

Many respirators have electrically-charged resin-impregnated particulate filters which are adversely affected by large doses of ionising radiation. Attention must be paid to this point in deciding the life of a filter, and also to a possible radiation hazard arising from the concentration of radioactive dust in the filter. In general, it is unlikely that the amount of radioactive dust deposited on the filter during the time the wearer of the respirator receives a tolerance dose from external radiation will have a significant effect on filtering efficiency.

References

(1) A.W.R.E. Report No. T22/57 - Operation 'Buffalo' Decontamination Group Report Parts 1-4 (Confidential)

7.7. Protective Measures

7.7.1. Introduction

Protection against the residual nuclear radiation from fallout presents a number of difficult and involved problems. This is so, not only because the radiations are invisible and require special instruments for their detection and measurement, but also because of the widespread and persistent character of the fallout. In the event of a surface burst of a high yield nuclear weapon for example, the area contaminated by the fallout could be expected to extend well beyond that in which casualties result from blast, thermal radiation and the initial nuclear radiation. Further, whereas the other effects of a nuclear explosion are over in a few seconds, the residual radiation persists for a considerable time.

The general protective measures which can be taken against fallout are as follows:-

(a) Remain in the contaminated area, but take all possible shelter from the radiation from fallout. Reference to Chapter 6 will show that considerable attenuation of gamma rays may be obtained by buildings and especially by earth-covered shelters.

(b) Removal of the population from a contaminated area to a clean or less contaminated one. This may result in greater exposure than by taking shelter, through having to travel without much protection through contaminated areas. At locations relatively near to ground zero, it may be necessary to wait several days before it is possible to come out of shelter without resking a radiation dose of sufficient magnitude to cause severe injury. The more distant a point in the path of the fallout is from the explosion, in the same general direction, the lower will be the initial radiation level, and the shorter will be the duration of the passive protection phase. However, in any area where the contamination is at all serious it will probably be necessary to spend the first day or two after the explosion sheltered from the residual gamma radiation. During the early stages, the activity of the fission products in the fallout is very high, but by the end of 49 hours, or roughly two days, it will have decreased to about 1 percent of the value at one hour after the explosion.

(c) Another protective measure which may be undertaken is decontamination after the fallout has settled. In many situations action of some kind can be taken to reduce the amount of fallout in critical regions, e.g. on roofs of houses and in streets. The whole subject of decontamination is dealt with in Chapter 8, to which reference should be made.

Details of a provisional scheme of public control in a fallout area are set out in a Home Office Memorandum (Reference (1)). This scheme is the accepted Government policy for Civil Defence against fallout.

Two detailed aspects of protective action against fallout will be discussed in this Chapter, namely, Protective Clothing (in Section 7.7.2), and Filters (in Section 7.7.3).

References

(1) Radioactive Fallout - Provisional Scheme of Public Control. Manual of Civil Defence, Vol. I, Pamphlet No. 2 (H.M.S.O.) (Restricted)

7.6.2. Surface contamination

The radioactive contamination of ground areas by fallout material (which was discussed in Section 7.5), gives rise to hazards which may be considered from two aspects. Firstly, the direct effect of the radiation exposure on human beings who might have to live and work in a contaminated area, and secondly, the indirect effects resulting from the consumption of food grown (and animals raised) in such a region. A full discussion of the many biological problems involved would be out of place in this manual. The calculation of exposure doses from fission products has been discussed in Chapter 3, Section 3.2 (External Residual Radiations) and leads to an estimate of the time that may be spent at a given location, provided that some limit is set for the total exposure dose. However, the value of such an emergency dose will depend on the conditions existing in the particular circumstances. A discussion of some of the factors involved will be found in Reference (1).

In contaminated agricultural areas the hazard to workers could be reduced by turning over the earth so as to bury the fallout particles (see Chapter 8, Section 8.6 for further details). But there still remains the question of the absorption of fission products from the soil by plants, and their ultimate entry into the human system in food. It is known that some elements are taken up more easily than others, but the actual behaviour depends on the nature of the soil and other factors. This highly complex problem is still being studied to determine the extent of the hazard which would result from the absorption of fission products by plants in various circumstances, and how it might be minimised. For recommended limits for the ingestion of radioactive substances see Chapter Section 3.3.

Danger during the fallout will also arise from the use of ventilation systems in places where shut-down would not be practicable, e.g. control centres. Ventilation plant dealing with large air flows could draw considerable quantities of the full concentration of fallout into the buildings. Deposition of this material inside the buildings could set up a radiation as well as a possible inhalation hazard. The provision of filters to combat this risk is discussed in Section 7.7.3.

References

(1) Hazards to Man of Nuclear and Allied Radiations (Medical Research Council, H.M.S.O. 1950), especially pp. 55-60.

7.6.3. Effects of weather on contamination by fallout

A factor which might contribute to the dispersal of active material would be the penetration of fallout into porous soil so that rain might help to contaminate soil in depth, whilst at the same time leaching out some of the soluble active constituents. The results of tests in which penetration was assessed suggest that it is of no practical significance.

In a trial (Reference (1)) conducted at Suffield, Canada, month-old fission products from a pile were spread out as a solution over an earth plot. It was found that the persistence of active material was influenced more by radioactive decay than by weathering loss. Two periods of heavy rainfall were not characterised by abrupt changes in the dose rate above the plot, while samples taken after a total rainfall of more than 3.5 inches showed that almost all the active material remained in the top 3 mm. of soil. As this included a rainfall of more than one inch in three days, which must have penetrated to a considerable depth, it was concluded that the washout by rain was very slight. Since soil is such an excellent filter for water, little or no contamination of water supplies is to be expected, other than that which actually falls into surface water.

In land reclamation tests carried out after Operation 'Jangle' (Reference (2)), it was found that the contaminant lay almost entirely on the surface, and that rain, after the explosion but before the tests, did not result in any significant penetration of the soil by the contaminant. The rain did, however, inhibit the movement of surface contamination by the wind.

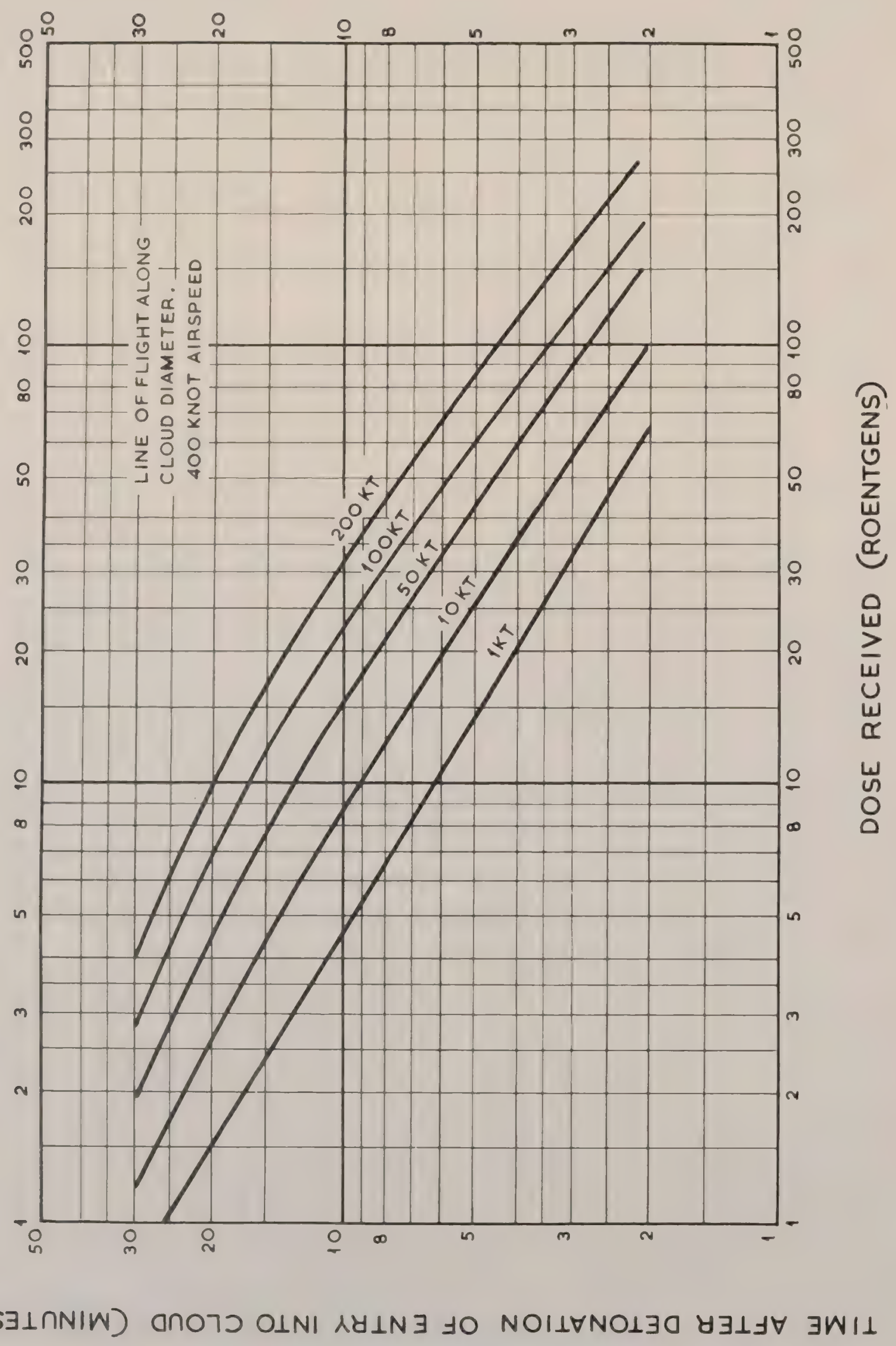
It was also observed at Operation 'Jangle' that light rain, which occurred six days after an underground burst, contributed to substantial decontamination of experimental buildings. The combined effects of wind and rain were thought in some cases to have caused building decontamination of the order of 90%.

The most spectacular effect of the weather on surface contamination noted at Operation 'Jangle' was the movement of large amounts of activity by high winds which persisted for several days after the test. Contamination near the crater area was moved downwind, and on the second day after the burst, activity levels at about a mile downwind were actually increased, in spite of decay. It is concluded that the movement of contamination from an underground or surface burst by winds could be a serious problem if dusty decontamination operations are undertaken during the first few days after a detonation. (See also Chapter 8 on Decontamination.)

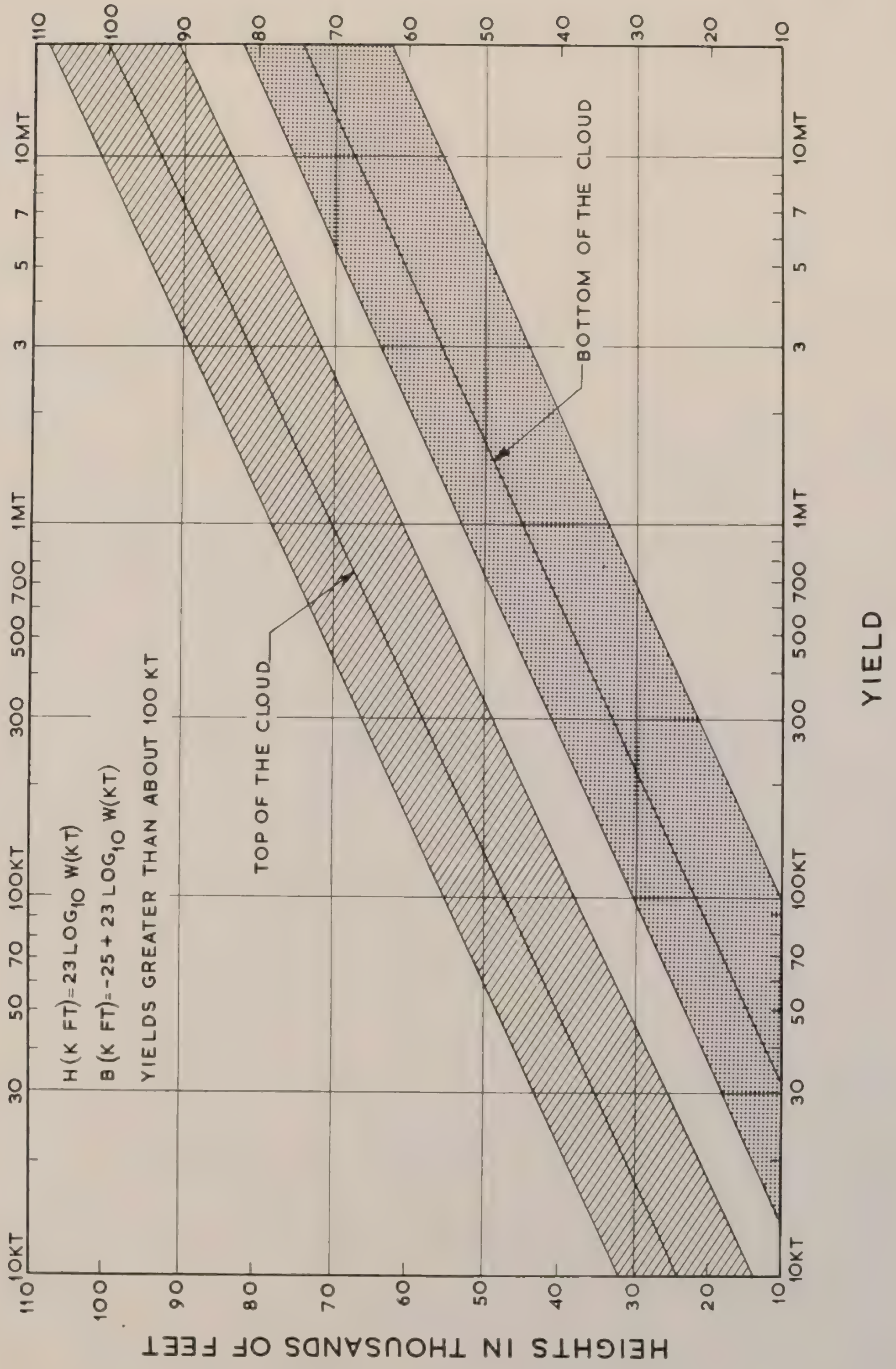
References

(1) Langstroth, G.O., Johnston, R.H., Hogg, B.G. and Fish, F.H. Suffield Technical Paper No. 18, August, 1952. (Secret)

(2) Operation 'Jangle' - U.S. Armed Forces Special Weapons Project Report No. WT-400. Project 6.2 "Protection and Decontamination of Land Targets and Vehicles". (Secret)



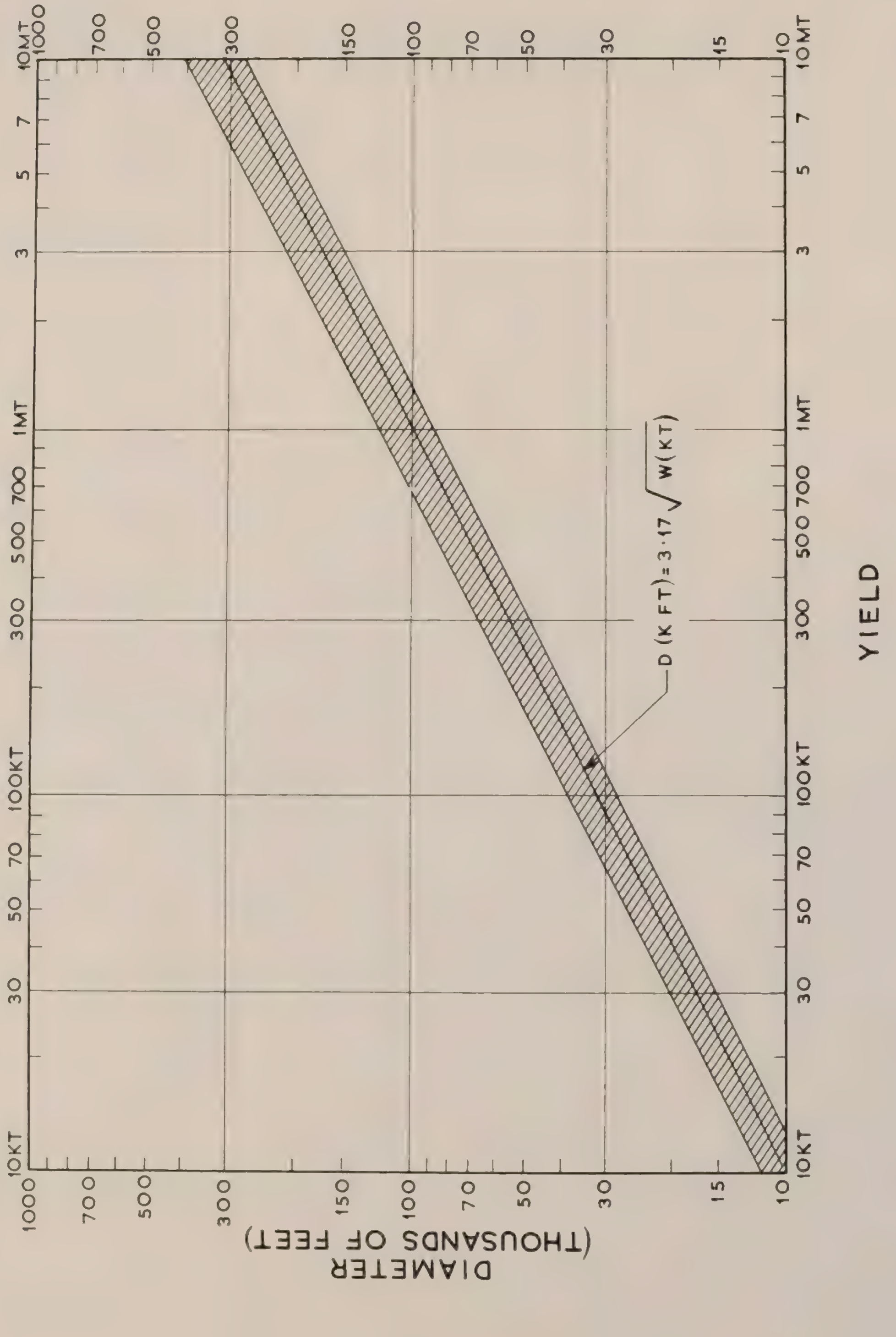
RADIATION DOSE RECEIVED FROM FLYING THROUGH AN ATOMIC CLOUD



DIMENSIONS OF STABILISED CLOUDS
IN CENTRAL PACIFIC

UNCLASSIFIED

D.N.W.
JAN.1958



DIAMETERS OF STABILISED CLOUDS
AS A FUNCTION OF YIELD

UNCLASSIFIED

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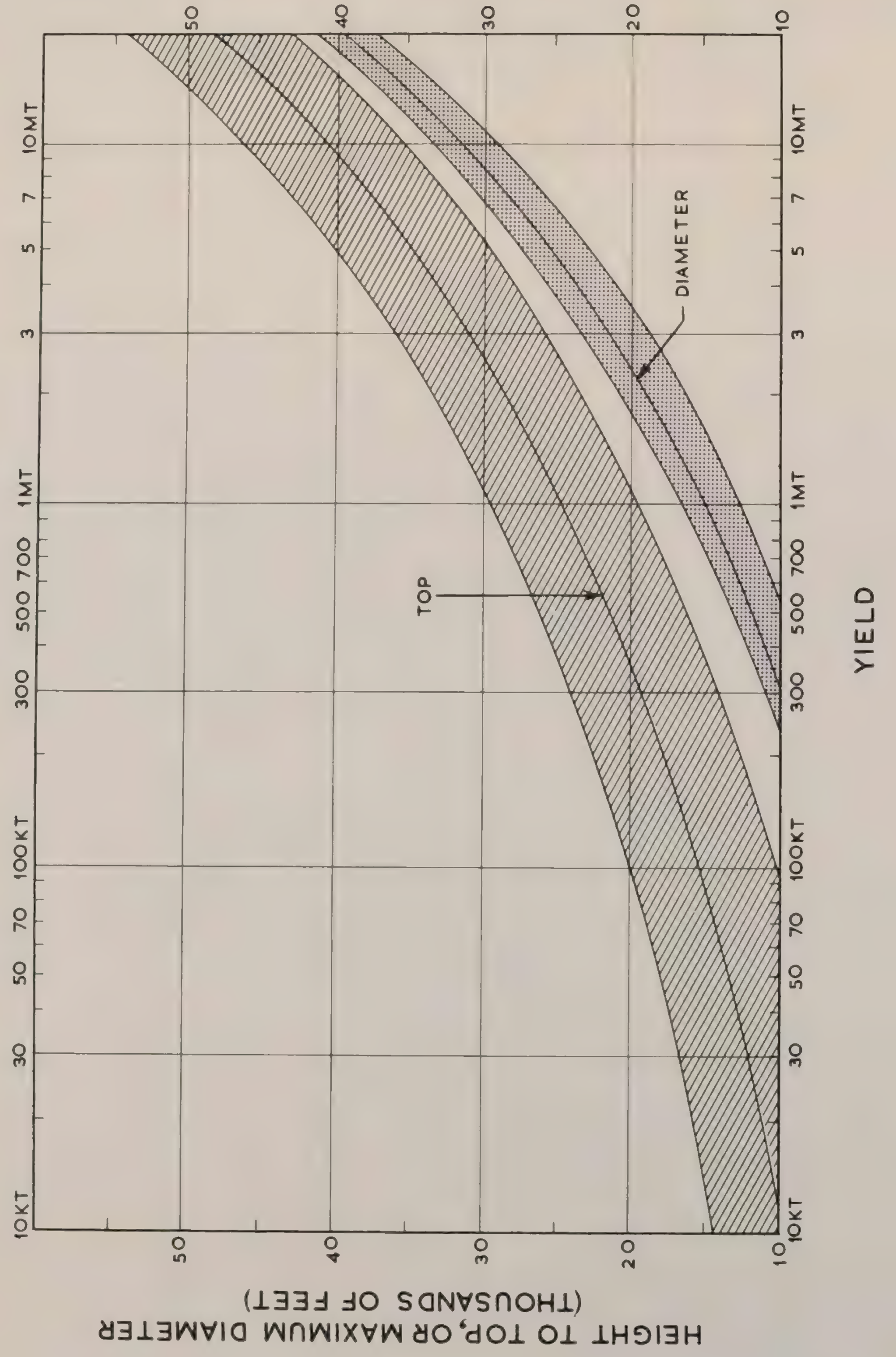
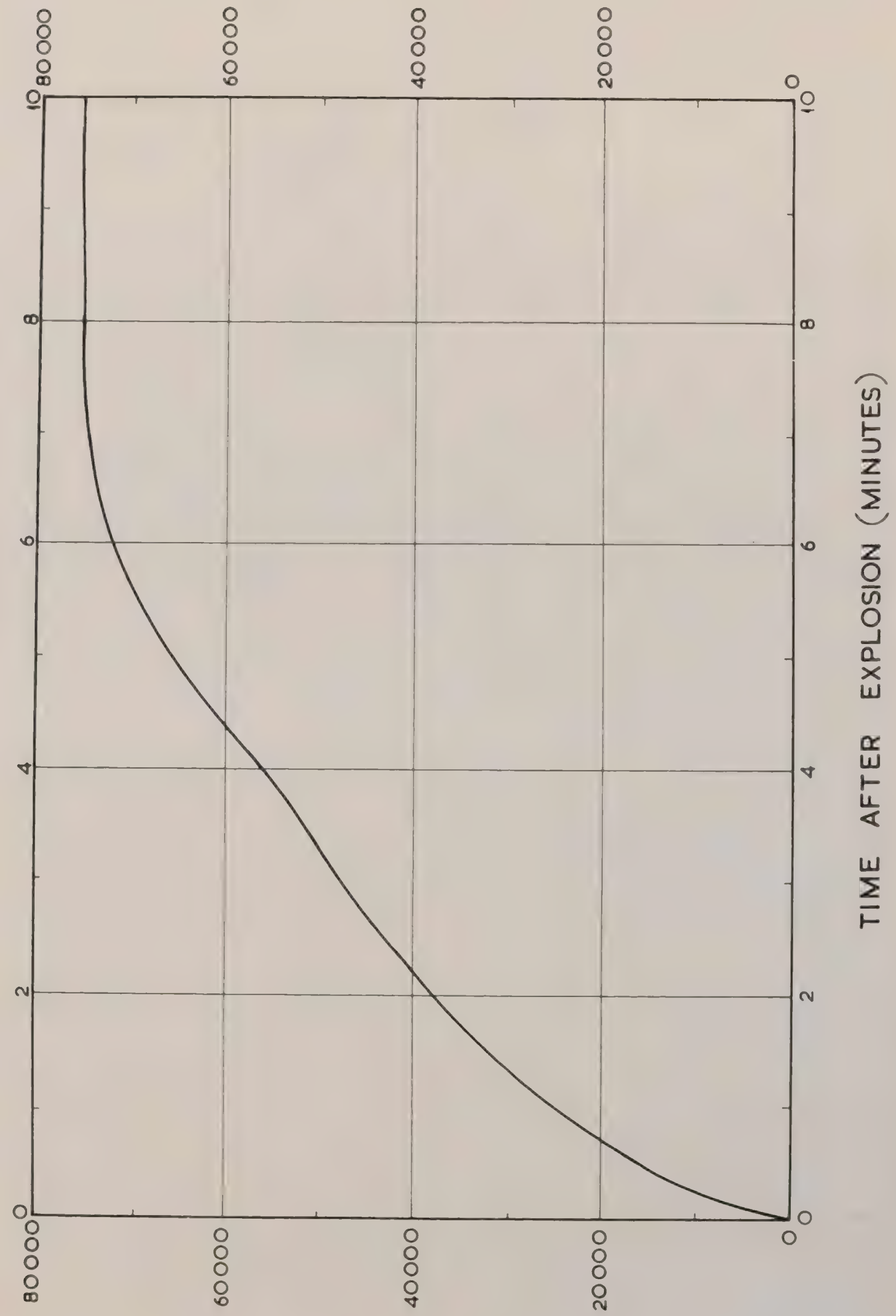


TOP AND DIAMETER OF VISIBLE
NUCLEAR CLOUDS AT 1 MINUTE

UNCLASSIFIED



HEIGHT OF CLOUD ABOVE BURST HEIGHT AT VARIOUS TIMES AFTER A 1-MEGATON EXPLOSION.

7.6 Hazards from Fallout

7.6.1 Cloud contamination

Radioactive particulate clouds at high altitudes could present a serious hazard to aircrews having to fly through them. In addition to the external gamma dose received during passage through the cloud, there would be the exposure of longer duration arising from the contamination of aircraft by the deposition of activity. Contamination would also occur in the event of the radioactive cloud being drawn into the aircraft through air supply systems, e.g. cabin pressurization systems.

The speed at which the top of the radioactive cloud ascends depends on the meteorological conditions as well as on the energy yield of the bomb. An idea of the rate of rise following a 1 MT burst is given by the results in Table 1, and the curve in Figure 1, which are both taken from Reference (1). In general, the cloud will have attained a height of three miles in 30 seconds, and 4.5 miles in about 1 minute. The average rate of rise during the first minute or so is roughly 260 miles per hour.

TABLE 1

Rate of Rise of Radioactive Cloud (1 MT)

Height (miles)	Time (minutes)	Rate of Rise (miles per hr.)
2	0.3	300
4	0.75	200
6	1.4	140
10	3.8	90
14	6.3	35

The eventual height reached by the radioactive cloud depends upon the heat energy of the bomb, and upon the temperature gradient and density of the surrounding air. The greater the amount of heat liberated, the greater will be the distance the cloud ascends. It is probable however, that the maximum height attainable by an atomic cloud is affected by the height of the top of the troposphere, i.e. by the base of the stratosphere, for atomic clouds which reach this level.

As a general rule the temperature of the atmosphere decreases with increasing altitude. However, in some circumstances an inversion layer occurs, where the temperature begins to increase with altitude. If the radioactive cloud should reach such a temperature inversion layer, it will tend to spread out to some extent. Nevertheless, due to buoyancy of the hot air mass, most of the cloud will usually pass through an inversion layer.

Upon reaching a level where its density is the same as that of the surrounding air, or upon reaching the base of the stratosphere, part of the cloud slows its rise and starts to spread out horizontally. This results in the formation of the mushroom-shaped cloud that is characteristic of nuclear explosions. The maximum altitude of the bottom of the mushroom-head, which is attained within about 8-10 minutes, is generally from 5-10 miles for a large burst. The top of the cloud rises still higher, the altitude increasing with the energy yield of the explosion. It is stated in Reference (1) that in tests with devices having energies in the megaton range, carried out in the

Pacific during 1952 and 1954, the tops of the clouds rose to heights of about 25 miles. The mushroom cloud generally remains visible for about an hour before it is dispersed by the winds into the surrounding atmosphere and merges with other clouds in the sky.

Some recent information concerning the height, dimensions and rate of rise of clouds from nuclear weapons has been given by Shelton (Reference (2)).

The height to top, and the diameter, of visible nuclear clouds at 1 minute, are given in Figure 2 (Reference (2)). Only surface bursts have been plotted and the widths of the bands are only sufficiently wide to cover the existing data. The wide scatter in cloud heights for surface bursts indicates that small variations in environment can give the same effect as a variation of a factor of 5 in yield. It is further stated, in Reference (2), that radioactive clouds rise in the atmosphere and stabilise at heights proportional to the logarithm of their yields. The dimensions of stabilised clouds in the Central Pacific are shown in Figure 3. For yields greater than 100 KT the following equations apply:-

$$H = 23 \log_{10} W \qquad (7.1)$$

and $$B = -25 + 23 \log_{10} W \qquad (7.2)$$

Where H = height of top of cloud (in Kilofeet)
B = height of bottom of cloud (in Kilofeet)
W = yield in kilotons.

Diameters of stabilised clouds are proportional to the square roots of the yields, and this is illustrated by Figure 4, from which it is seen that:-

$$D = 3.17 \sqrt{W} \qquad (7.3)$$

Where D = cloud diameter (in Kilofeet)

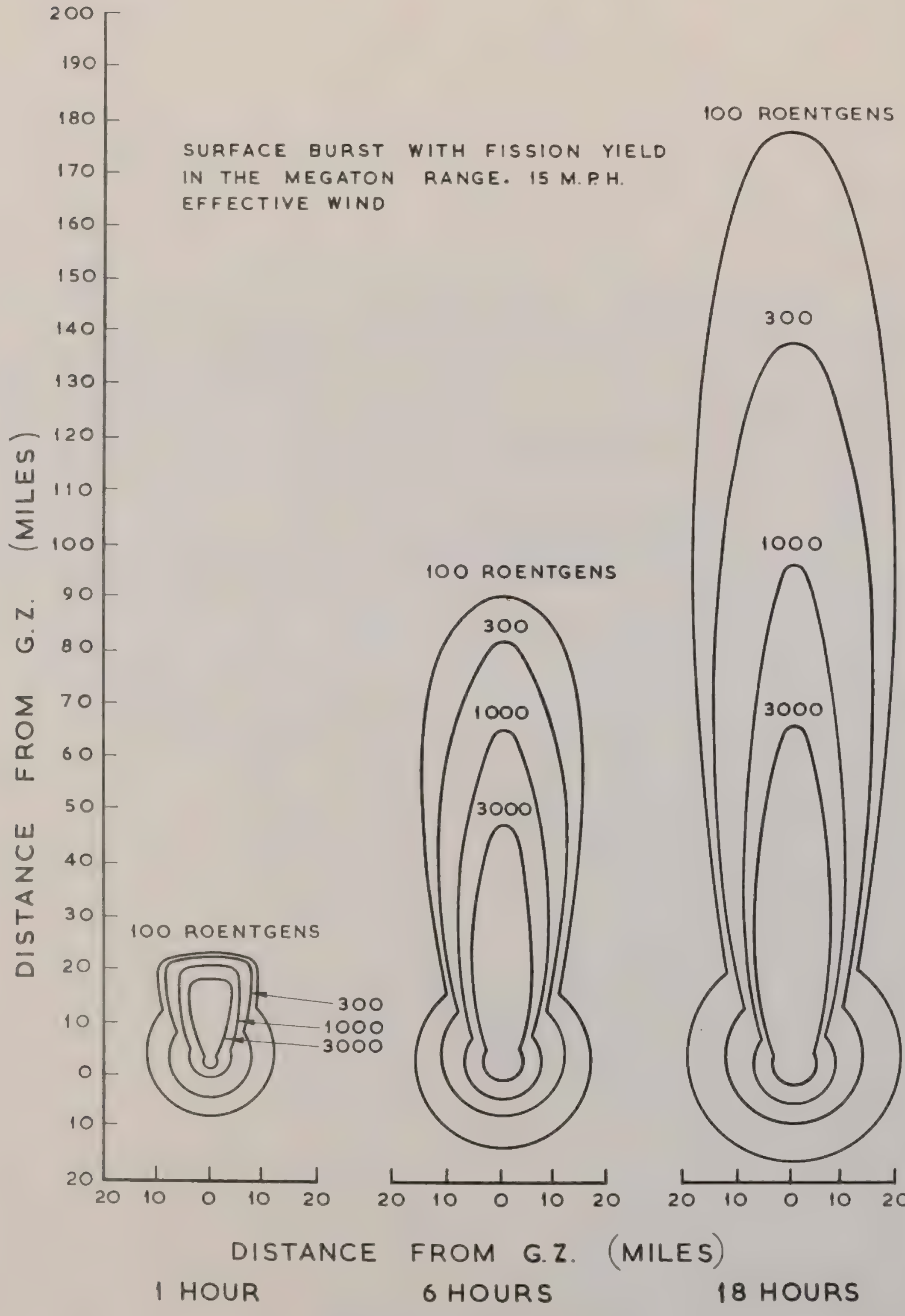
The dose received by personnel in aircraft flying through an atomic cloud at various times after detonation, may be read from Figure 5 (obtained from Reference (3)). This Figure gives the dose that is received for various weapon yields for a particular air speed, and may be converted to other air speeds by the approximate relation that if the aircraft is travelling twice as fast, its crew will receive half the dose; and if it is travelling half as fast, the crew will receive twice the dose. It should be noted however, that account does not appear to be taken of the dose from contamination collected by the aircraft.

References

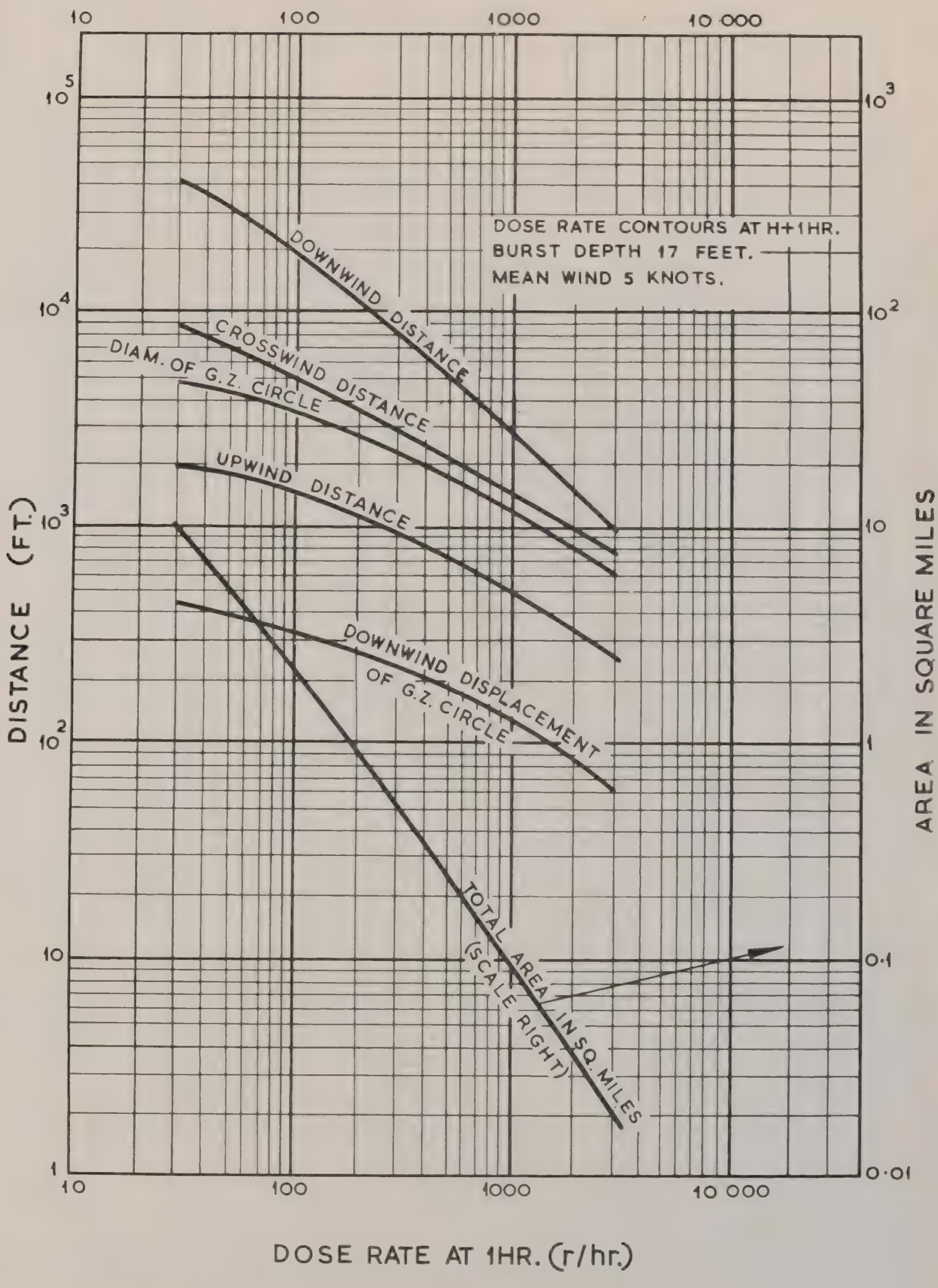
(1) Effects of Nuclear Weapons, U.S.A.E.C., 1957, pp.21 and 23.

(2) Shelton, F. H. - "The Physical Aspects of Fallout" Tripartite Conference on The Effects of Atomic Weapons, 1957.

(3) Capabilities of Atomic Weapons, 1955. A.F.S.W.P. TM-23-200 (Confidential/Atomic) Figure 29.



TOTAL (ACCUMULATED) DOSE CONTOURS FROM FALLOUT-MEGATON SURFACE BURST



DIMENSIONS FOR CONTAMINATION PATTERNS
1KT UNDERGROUND BURST

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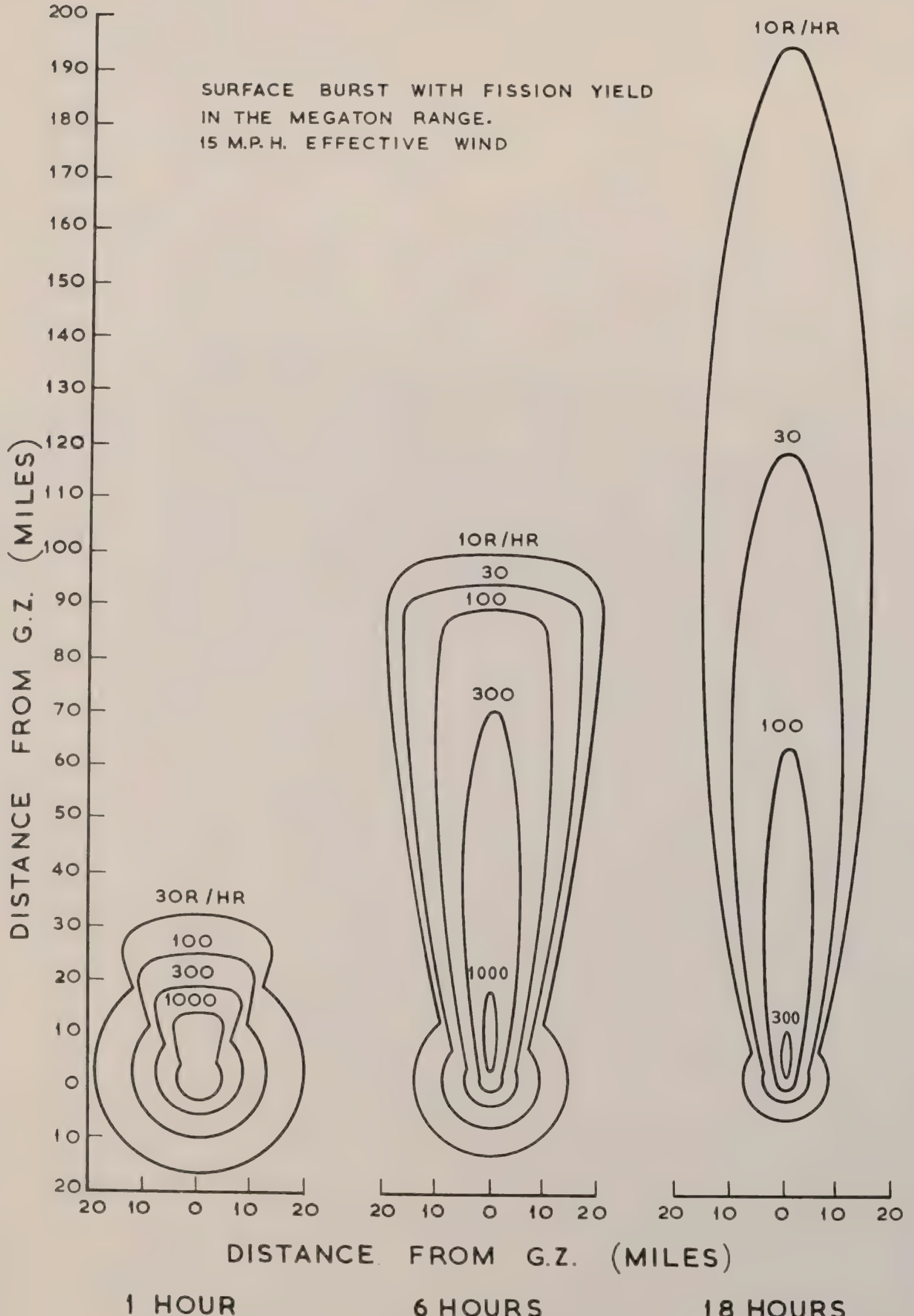

DOSE-RATE CONTOURS FROM FALLOUT—
MEGATON SURFACE BURST

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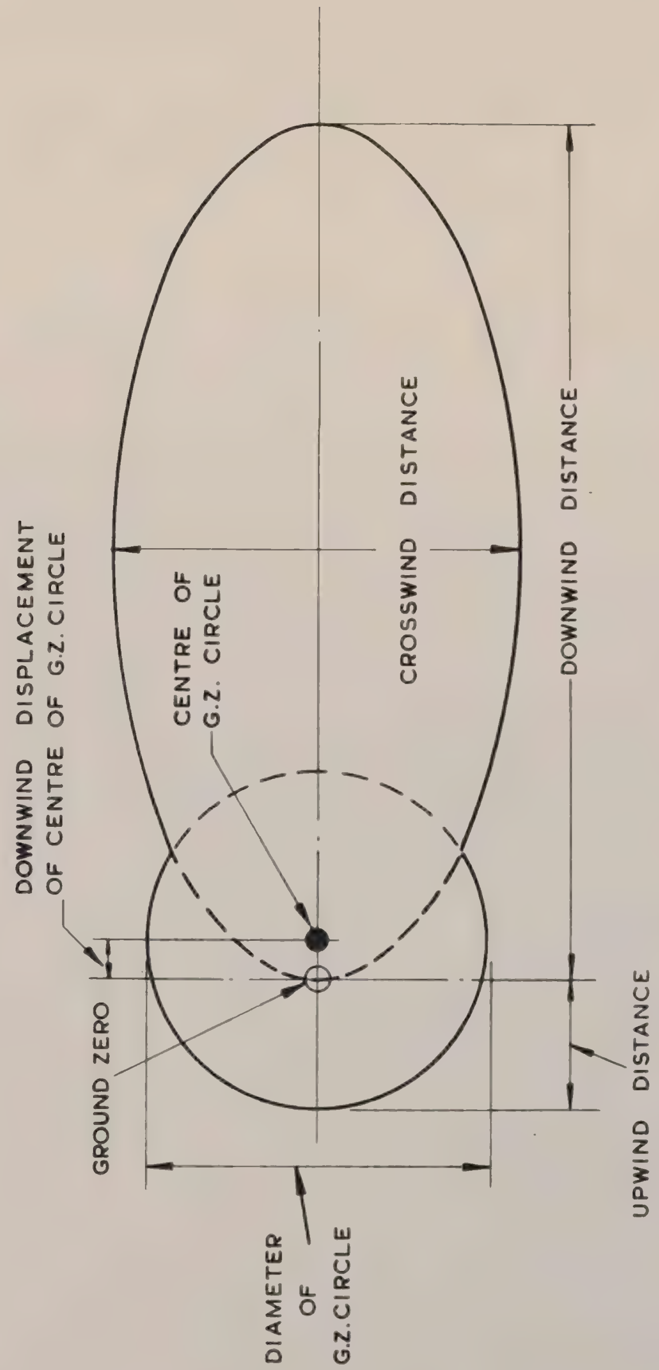
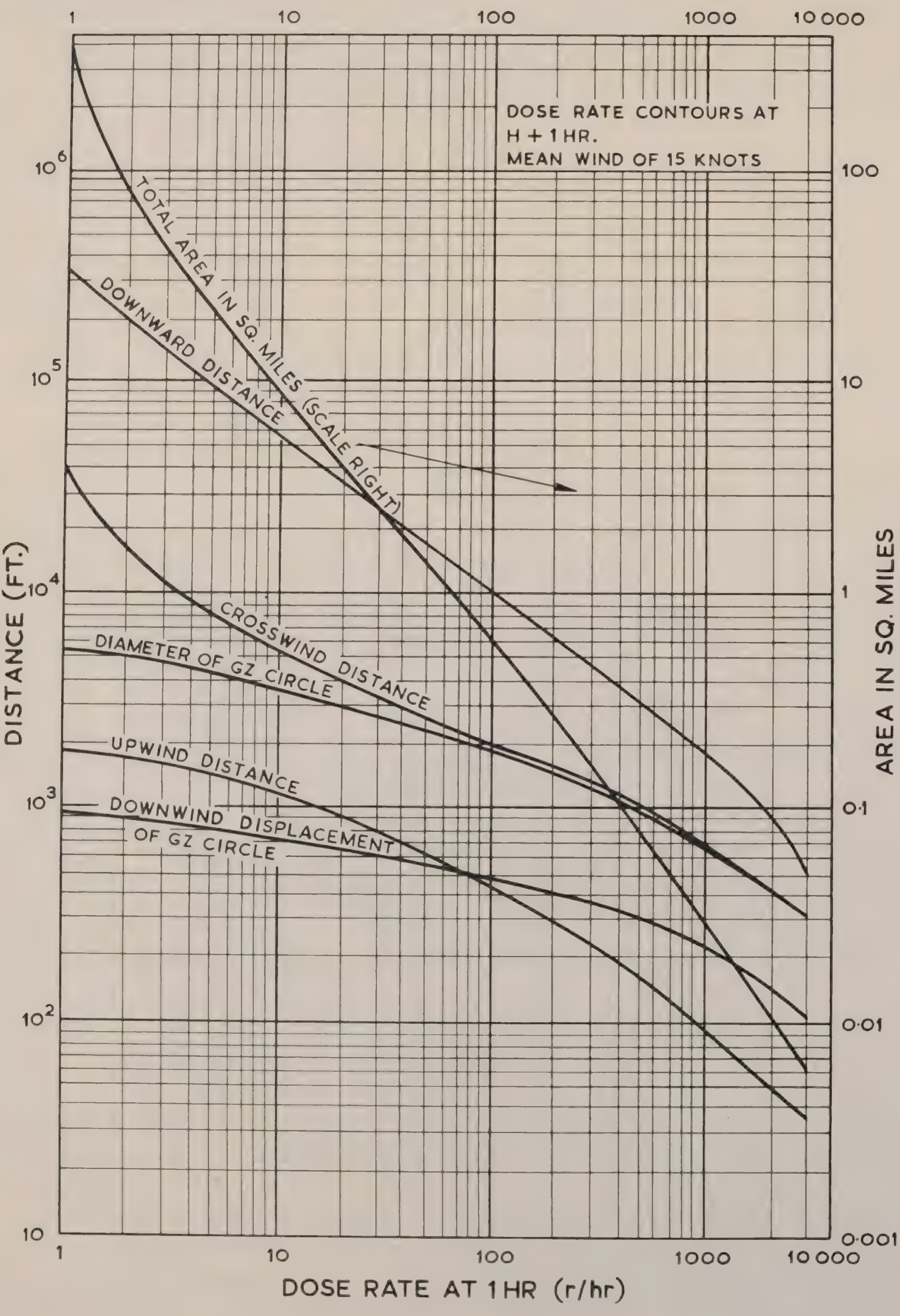


GENERALISED FALLOUT PATTERN

CONFIDENTIAL
U.K. EYES ONLY

D.N.W.
FEB. 1958



DIMENSIONS FOR CONTAMINATION PATTERNS
1 KT SURFACE BURST

CONFIDENTIAL / U.K. EYES ONLY

TABLE 1

Calculated Radiation Doses at Two Locations
in Ronglap Atoll from Fallout Following the March 1st, 1954,
Test at Bikini

Exposure period after the explosion	Accumulated dose in this period (roentgens)	
	Inhabited location	Uninhabited location
First 36 hours	140	2,150
36 hours to one week	101	1,310
One week to one month	73	950
One month to one year	83	1,080
Total to one year	397	5,490
One year to infinity	about 129	1,680

The following observations on the close-in time of arrival of fallout and the build-up of activity, are due to Shelton (Reference (3)).

Fallout from an overland surface burst of about a megaton will begin to arrive on the ground over an area the order of the size of the visible cloud, almost like a blanket, at about 15-20 minutes following detonation. Fallout from a shot of the order of a megaton on a barge in water will begin to arrive at the surface after about 30-40 minutes. These times of arrival of the first fallout are related to particle size, the land shot fallout having the larger median particle size.

A law relating the time of arrival of fallout and peak radiation intensity, has been stated by Shelton as follows:-

> If fallout begins at a given place at t_a (hours) after detonation, then the peak dose-rate will be at $2t_a$(hours) and fallout will cease at about $5t_a^{0.7}$ (where t_a in the latter case has been less than, or equal to about 13 hours).

This leads to the conclusion that the time of peak activity approaches the time that fallout ceases as the time of arrival increases.

Reference should be made to Chapter 3, Section 3.2, for details of the critical doses and contamination levels from residual radiations, and also to Chapter 7, Section 7.6, which discusses the hazards from fallout.

References

(1) Hicks, E.P. "United Kingdom Method of Predicting Fallout Beyond 10 miles - Criteria used at Maralinga".
Tripartite Conference on The Effects of Atomic Weapons, 1957.

(2) Effects of Atomic Weapons, U.S.A.E.C. 1957, Chapter 9, pp 408-427.

(3) Shelton, F.H. - "The Physical Aspects of Fallout".
Tripartite Conference on The Effects of Atomic Weapons, 1957.

(4) Residual Contamination of Plants, Animals, Soil and Water of the Marshall Islands, Two Years' following Operation Castle Fallout.
U.S.N. R.D.L.- 455. NS-081-001. 15th August, 1956.
(Discreet/Military Use Only).

7.5. Areas of Contamination.

Contamination from long-range fallout is world wide, but owing to its wide dispersal and slow rate of deposition it cannot be attributed to any particular incident; it arises from the gradual build-up of deposits from an increasing number of nuclear explosions. Similarly, the hazards associated with it will be due to the slow cumulative build-up of dangerous radioactive isotopes of long half-life, e.g. Strontium 90. The contamination which can be associated with a particular incident will be that arising from medium and short-range fallout, and it is the areas of such contamination that are discussed here.

As the hazards from this type of contamination arise mainly from the external radiation, it is customary to express the areas of contamination in terms of radiation dose-rates.

Because of the complex and variable factors which influence the deposition patterns it is virtually impossible to predict the detailed pattern of contamination arising from any particular explosion. However, by recourse to an idealised fallout pattern it is possible to derive nominal fallout patterns, which can then be modified in the light of practical experience. For this purpose the complicated wind structure extending from the ground to the top of the cloud is replaced by a single mean wind. The apparent velocity of the mean wind is roughly determined by averaging the scalar velocities of the resultant winds from all altitudes between the top and bottom of the stabilised bomb cloud. A resultant wind vector for a given altitude is the vector average for all wind vectors from that altitude down to the surface. Through the concept of a single mean wind, and the use of appropriate scaling factors, it is possible to compute the idealised fallout pattern corresponding to any circumstances.

A more elaborate method of predicting fallout beyond ten miles has been developed by Hicks (Reference (1)) and used at British Trials at Maralinga.

The general features of the fallout pattern are as follows. Ground contours of equal gamma dose rate consist of two overlapping curves,

(a) Ground Zero circles whose centres are displaced a short distance downwind of Ground Zero.

(b) Down-wind ellipses having one vertex at Ground Zero and major axis extending in a down-wind direction.

These features are illustrated in Figure 1.

For a given explosion, the dimensions of the Ground Zero circles and down-wind ellipses are determined by the dose-rate of which these curves are the contour. The data are thus conveniently expressed graphically, the dimensions and areas of the contamination contours being plotted against dose rate, usually referred to a time of H + 1 hours (one hour after the explosion).

The dimensions of the idealised dose-rate contours for a 1 KT surface burst fired in a mean wind of 15 knots, are given in Figure 2 (taken from M.E.A.W., Figure 6.3.1.). Corresponding data for surface bursts of other yields and wind speeds can be obtained from the following scaling laws (reference M.E.A.W, Data Sheet 6.3.3.).

(i) Variation with weapon yield. Multiply all linear dimensions and also the value of the dose rate by $W^{\frac{1}{3}}$, where W is the total yield in kilotons.

(ii) Variations with wind speed. Multiply the down-wind displacement of the Ground Zero circle and the down-wind length of the ellipse by the cube root of the wind speed ratio, i.e. by $\left(\frac{S}{15}\right)^{\frac{1}{3}}$ where S is the wind speed in knots. Divide the cross-wind breadth of the ellipse by the cube root of the wind speed ratio. The radius of the Ground Zero circle, areas of both circle and ellipse, and the value of the dose-rate on these contours, are all unchanged.

Another factor which can affect the fallout dose-rate contours is the degree of contact between the fireball and the ground. Contamination data for a 1 KT weapon exploded underground at a depth of 17 ft. in a 5-knot wind, are given in Figure 3, (taken from M.E.A.W, Figure 6.3.2.). The scaling laws stated in the previous paragraph give corresponding data for other wind speeds and yields of weapon exploded underground at a scaled depth of 17 $W^{\frac{1}{3}}$ ft.

Some indication of the manner in which the fallout pattern develops over a large area during a period of several hours following a nuclear surface burst of high yield is illustrated by Figures 4 and 5, taken from Reference (2). The mean wind velocity was taken as 15 miles per hour. Figure 4 shows a number of contours for certain arbitrary values of the dose-rate, as would actually be observed on the ground, at 1, 6 and 18 hours respectively after the explosion. A series of total or accumulated dose contours for the same times are given in Figure 5. It will be appreciated that the various dose-rates and doses change gradually from one contour line to the next. Similarly, the last contour line shown does not represent the limit of the contamination, since the dose-rate and dose will fall off steadily over a greater distance.

In general, at any given location at a distance from a surface burst, some time will elapse before the fallout arrives. This time will depend on the distance from Ground Zero, the time taken from the particles to descend to earth, and the mean wind velocity. When the fallout first arrives the exposure dose-rate is small, but it increases steadily as more and more fallout descends. In a few hours the fallout will be mainly (although not absolutely) complete, and then the radioactive decay of the fission products will be accompanied by a steady decrease in the dose-rate. Until the fallout commences, the total dose will be zero, but after its arrival, the accumulated radiation dose will increase continuously, at first rapidly and then somewhat more slowly, over a long period of time, extending for many months and even years (see Table 1, taken from Reference (2)).

7.4. Radioactivity of Fallout

The radioactivity distributed amongst the particulate matter will depend on the size and also on the type of weapon. Data on the distribution of the activity in the form of radioactive particles are very limited, but there is evidence, based on the analysis of samples corresponding to long range fallout, i.e. samples consisting mainly of spherical particles and with maximum diameter about 20 microns, that specific activity generally decreases with increasing particle size.

As more and more data are accumulated on the characteristics of fallout from nuclear tests, it is becoming increasingly evident that there is a quantitative correlation between particle size and specific activity only in the case of air bursts, i.e. where no dilution with inert material occurs. No such correlation is likely to be found in the case of ground burst weapons.

As would be expected, significant differences have been found in the specific activity of particles of the same size from different explosions, e.g. the specific activity of 6-micron diameter particles expressed as $d.p.m./d^3$, where d.p.m. is the number of disintegrations per minute and d is the particle diameter in microns, has been found to vary between a low value of 0.3 and a high value of 50 at a time of 25 days after burst. Even in a given sample the specific activity of particles of the same size has been found to vary as much as about thirtyfold.

Further studies may reveal some factor of general application relating activity with particle size, but at present no conclusions of value to target response problems may be drawn.

7.3. Effect of Particle Size on Dispersion and Deposition

The dimensions of the cloud, its height and its movement are controlled by the size of the weapon, by the type and site of the burst and by the prevailing weather conditions, while the deposition of the particles from it is also dependent on the size distribution of the particles throughout the airborne particulate material. The dispersion and deposition patterns can be divided into three main groups based on a classification of particles as fine, medium and large, and giving rise to long, medium and short range of fallout respectively.

Fine particles are carried to considerable heights and in the case of megaton weapons a large proportion may pass into the stratosphere. The particles from the troposphere also settle very slowly but their deposition may be accelerated through scavenging by rain. It has been estimated that it takes about a month for particles to be deposited from the troposphere, and also that it takes on average about seven years for half the particles in the stratosphere to find their way into the troposphere. Two patterns for the deposition of fine particles are possible. When the particles are confined to the troposphere they will, during the comparatively short deposition time, be carried round the earth and eventually be deposited as a broad band at the latitude of burst. On the other hand particles which are carried into the stratosphere will be widely dispersed before they return to the troposphere and will eventually be deposited at the rate of about 10 percent every year over the surface of the earth.

Medium sized particles are those with moderate settling speeds. While settling they will be carried by the down wind, with some crosswind spread, and so will be deposited in elongated cigar-shaped patterns downwind of ground zero.

Large particles settle very quickly and consequently are not widely dispersed before deposition. They are composed of material from the ground carried upwards by the explosion and are derived mainly from the mushroom stem associated with ground or near ground bursts. They are found deposited in a roughly circular pattern within comparatively short distances of ground zero.

The patterns of deposition are considered in greater detail in Section 7.5.

Only in the case of a true air burst are the particles likely to cover a comparatively narrow size range; in all other cases the particulate matter will cover a very wide range of sizes.

The distinction drawn at the beginning of this section between the three types of fallout cannot be sharp, and there will be some overlap of particle size range but, as they are based on a rough size classification, it is convenient to consider particle size distributions in terms of the fallout pattern.

Composition of long range fallout

Results are based on the analysis of samples collected by aircraft equipped with special sampling filters. Some clouds have been sampled at a considerable height shortly after burst, and also after travelling thousands of miles, while others have been sampled only at long distances from ground zero. No particles larger than about 20 microns diameter have been found in any of the samples. Although the size range of particles is known in general terms, data for mass distribution of particles visible under the optical microscope are available in only one case. A sample from an air burst in which activity was found to be proportional to volume of the particles gave the approximate mass distribution, based on activity measurements, as:

Diameter Range (microns)	0 - 3	3 - 6	6 - 9
% Mass in range	30	30	30

This distribution, together with about 10% of the mass in the diameter range 9 - 30 microns may be regarded as being fairly typical of long range fallout.

Composition of medium range fallout

The smallest particles in this type of fallout will overlap the largest particles in the long range fallout, but it is not expected that an appreciable mass of medium range fallout will consist of particles less than about 10 microns diameter. A theoretical analysis of fallout has indicated that most of the contamination downwind of the position of deposition of 300 microns diameter particles comes from the cloud and not from the stem, and this diameter may be taken as the top size in medium range fallout.

Particles in medium range fallout will therefore cover the approximate diameter range 10 - 300 microns, but the overall distribution of sizes within this diameter range will depend on all the factors influencing the formation of the particulate cloud which have already been mentioned. Gradation of sizes will also take place downwind along the track of the fallout, the larger particles settling first, and the actual distribution of sizes downwind will not follow a pattern that can be predicted with any precision.

By analysing the very limited data for the cloud from a ground burst megaton weapon a few hours after burst, and those for actual deposits on the ground from this and other ground burst kiloton weapons, it has been possible to derive a size analysis which indicates the type of overall distribution to be expected in medium range fallout. This is:-

Diameter range (microns)	0-5	5-10	10-20	20-30	30-40	40-50	50-60	60-80	80-100	>100
% Mass in range	1.0	2.0	7	12	18	15	12	15	8	10

Composition of short range fallout

Particles deposited as short range fallout have sizes from about 300 microns diameter to the largest particles falling from the mushroom stem. It is not possible to set an upper limit to the size, nor to state a size distribution. Radioactive particles several mm in diameter have been found in column fallout.

References

(1) The Effects of Nuclear Weapons. USAEC. 1957.

(2) Operation Greenhouse. Scientific Directors Report, Annex 4.6. Atmospheric Conductivity. Air Force Cambridge Research Centre Report WT-71, Sept. 1951. (Secret)

(3) Radioactive Fallout and Radiostrontium. Dr. Willard F Libby, USAEC. A.E.C. Press Release January 19th, 1956.

(4) The Nature of Atmospheric Dust. Radioactive and Electron Microscope Measurements on Fallout on Princeton, N.J., 1954-5. Heininger and Turkevitch. TIL P65414.

CHAPTER 7 - PARTICULATE CLOUDS FROM NUCLEAR WEAPONS

7.1. Introduction

Particulate matter produced in a nuclear explosion may give rise to radioactive hazards:-

(a) as an airborne cloud

(b) after deposition on the ground as fallout

(c) on re-dispersal, for example during decontamination operations.

The formation of this particulate matter will depend on the nature and size of the weapon, and on the site of the explosion; its subsequent history will be largely influenced by the prevailing meteorological conditions. Because of these complex and variable factors it is not possible to predict accurately the behaviour of the particulate matter in any one incident. It is possible, however, to give a general account of the properties of particulate clouds produced by nuclear weapons and to estimate the magnitude of the hazards associated with them.

It is the intention in this chapter, therefore, to present a broad outline of the formation, despersion and deposition of the particles in clouds, and to examine, with the aid of such information as is available, the special problems arising from the radioactivity of the particulate matter from nuclear weapons.

7.2. Formation

The radioactivity of the particulate matter associated with a nuclear explosion arises from the fission products and neutron absorption products of any tamper present. The active products are vaporised with any other material enclosed within the fireball, and as the fireball rises and cools, they condense to form the radioactive particles. Depending on the conditions and type of burst the active products may condense to form spherical particles with activity distributed throughout the particles, or in condensing, some may become associated with inactive material to form radioactive particles of various shapes and sizes, with the activity distributed in various ways. Some particulate matter associated with the burst may not be affected by the condensation of the fission products and the cloud may therefore contain both active and inactive particles.

In an air burst, the bomb debris, consisting largely of active material, condenses into very small solid particles. In this finely divided state a portion of the radioactive particles enter the stratosphere and remain suspended for several years, circulating the earth several times before reaching the surface. During this period they will decay, so that when they reach the earth's surface they will be widely dispersed and their radioactivity will be very greatly reduced, although they will still not be innocuous.

In certain weather conditions, e.g. a warm front rainfall situation, there might be appreciable fallout of a localised character owing to particles of bomb residue attaching themselves to water droplets which subsequently fall as rain. (See also Chapter 3, Section 3.2.).

An air burst of a small yield weapon would not be accompanied by serious local fallout except under special conditions such as the rainfall situation mentioned above. This is confirmed by the fact that there were no casualties in the nuclear bombing of Japan that could be attributed to residual radiation. Observations made at tests indicate that the local fallout from air bursts is also small for large yield weapons - Reference (1).

In a surface burst however, large amounts of earth, dust and debris are taken up into the fireball and ascend with it in its early stages. The material within the fireball is fused or vaporised and becomes intimately mixed with the active material, so that on cooling a very great number of contaminated particles is produced.

Other material which is sucked up with the fireball, but is not exposed to the highest temperatures, may not even be fused, although it will become contaminated with particles of condensed active products.

The larger particles, which would include a great deal of contaminated material scoured and thrown out of the crater, will not be carried up into the mushroom cloud, but will descend from the column. With some soils a base surge may be formed. Provided the wind is not excessive, this large particulate material will fall to form a roughly circular pattern around ground zero. This material will descend within a short time, not more than an hour or so from the time of burst. The smaller particles present in the atomic column are, however, carried upwards to a height of several miles, and may spread out some distance in the mushroom cloud before they begin to descend. The dispersion of these particles is considered in Section 7.3.

References

(1) The Effects of Nuclear Weapons, U.S.A.E.C., 1957, p. 49, p. 409.

6.5. Protection Afforded by Clothing

Ordinary temperate zone clothing provides negligible protection against extermal gamma radiation, considerable protection against the lower energy beta radiations, and complete protection against alpha particles. Its value in the cases of beta and alpha emitters depends largely on the extent to which it can keep the radioactive particles away from contact with the skin. Particular care must be taken to avoid the risks of fallout material being rubbed into the skin at the edges of clothing as at neck, wrists and ankles. A detailed discussion of the design considerations for protective clothing will be found in Chapter 7, Section 7.7.2.

6.6. Shielding by Vehicles

Considerable shielding is afforded in armoured vehicles required to operate through areas contaminated by residual radiation. The integral dose received by crew members, in general, is less than 10 per cent of the dose that would be received outside the vehicles. Personnel riding on the mudguards of vehicles will receive, roughly half the dose they would receive if they were on foot (Reference (1)).

Reference

(1) Operation Jangle - U.S. Armed Forces Special Weapons Project Report No. WT-400. (Secret)

6.4. Shielding by Some Common Structures

Measurements of the protection afforded by model houses against residual radiation were obtained at Operation Buffalo, and are reported in Reference (1).

Calculations on the shielding value of slit trenches against nuclear radiations are given in Reference (2).

Some measure of protection to roadways and open areas may be given by the erection of suitable earth barriers. This is discussed in Chapter 8, Section 8.3.6.

The protection afforded by a building or shelter against gamma-radiation from fallout may be expressed as the "protective factor". This is defined as the factor by which the dose rate received by a person in the building is reduced, compared with that received by a person standing in the open, or more accurately, on an infinite flat plane.

Two main difficulties arise in any attempt to calculate accurately the protective factors of buildings and shelters in general. The first difficulty is the complexity of the geometry involved (owing to the presence of doors, windows, chimney breasts, etc.) and the second concerns the uncertainty of the actual distribution of fallout material on the roof and walls of the building. Irregularities in fallout distribution on these areas are likely to arise from the slope and nature of the surface, and also from the effects of wind and weather.

A simple and rapid method of making a rough assessment of the protective factors of buildings and shelters is given in Reference (3). The basis of this scheme is to carry out the initial calculation in terms of an arbitrary "points scheme", awarding 1,000 points to a completely unprotected location (i.e. an infinite flat plane) and reducing the points for other situations in direct proportion to their protective factors. Thus, once the "points" value of a particular building have been calculated, its protective factor is given by:-

$$\text{Protective factor} = \frac{1{,}000}{\text{"Points" value}}$$

Separate consideration is given, and appropriate "points" calculated, for the radiation coming from each of five directions, that is, from the roof and the four walls. For each of these directions the "geometrical" points are first determined, that is the points which derive solely from the distance factor and depend on the size and height of the building. These "geometrical" points are then multiplied by the attenuation fraction resulting from the shielding material between the shelter and the fallout, to give the total roof or wall points as the case may be. These five sets of points are then added up to give the final value for the accommodation.

An assessment of the accuracy of the method has been obtained by comparing calculated values for protective factors with those given by field experiments using radioactive sources. It is concluded that:-

(i) Where the geometry of the shelter is simple (e.g. a brick surface shelter) results given by the points scheme should not be in error by more than 50 percent, and may be considerably better.

(ii) For complicated structures (e.g. the ground floor of a 19th century Government building), results given by the points soheme may be in error by a factor of 3 or 4. In these complicated cases the points scheme tends to under-estimate the protection given, so that results given by this scheme should be at least on the safe side.

See Reference (4) for the published version of this technique, with worked examples.

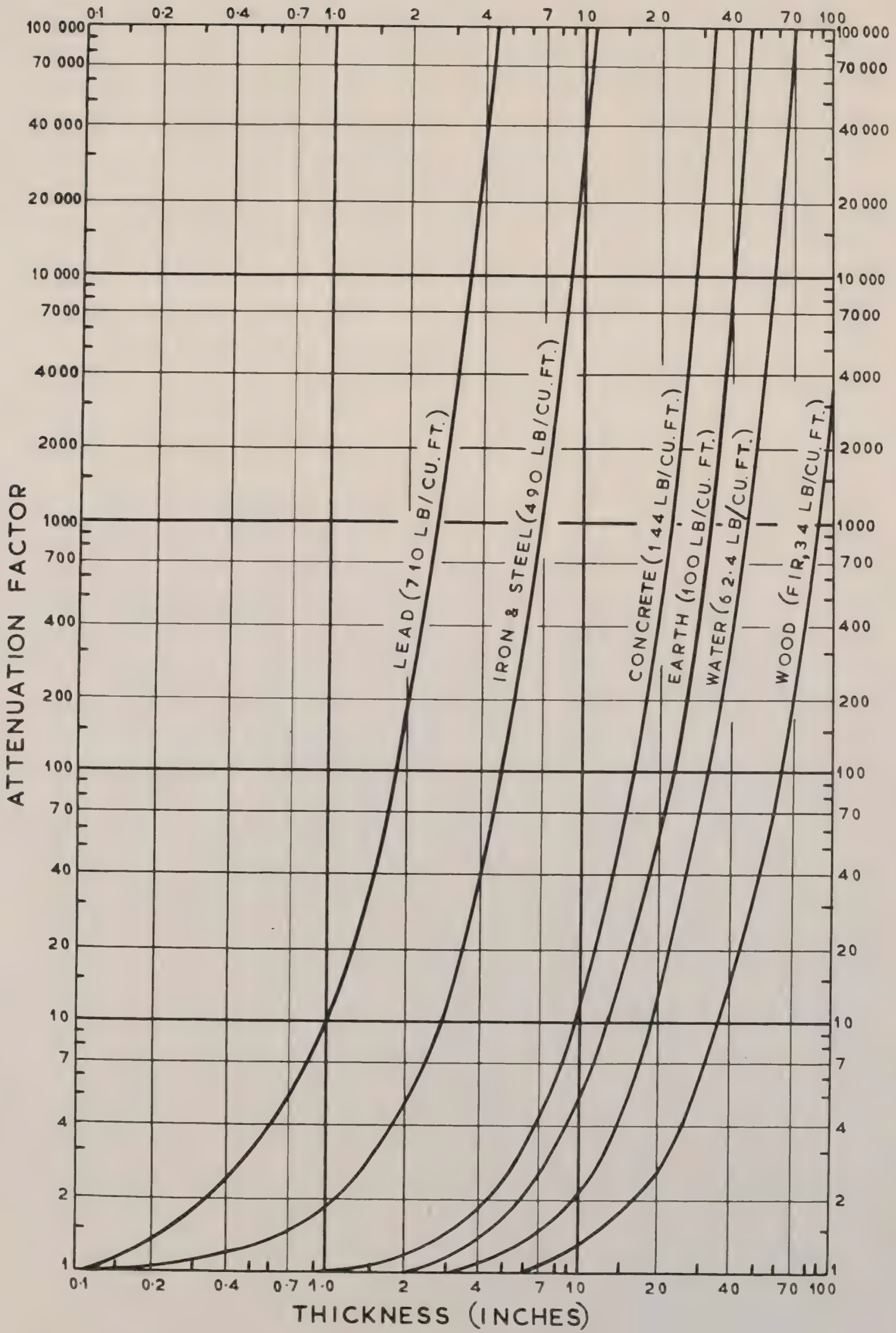
References

(1) Tripartite Conference Report TCR 7/57 by A.M. Western (Confidential)
(To be published later as an A.W.R.E. Report).

(2) A.O.R.G. Report No. 12/55 - "The Protective Value to Personnel of Slit Trenches against Thermal and Gamma Radiation Effects of Nuclear Explosions. (Secret/U.K. Eyes Only)

(3) Home Office Report CD/SA 68, 1956 - "Protection Against Gamma-Radiation from Fallout" (Confidential)

(4) Home Office Publication "Assessment of the Protection Afforded by Buildings against Gamma-Radiation from Fallout", (1957). H.M.S.O.



ATTENUATION OF FISSION PRODUCT RADIATION

D1/57
March, 1958.

Part VII
Chapter 6
Section 6.3

6.3. Shielding from Residual Gamma-Radiation

The mechanism by which this radiation interacts with matter are the same as those described for initial gamma-radiation. Attenuation factors for various shields can be calculated from Figure 1, Section 5.1.4 of Chapter 5, on Shielding against initial gamma-radiation, but a lower mean energy will be appropriate. In this matter there is no evidence of any difference between kiloton weapons and megaton weapons. An average energy of 0.7 Mev has been recommended (Reference (1) p.402), but calculation (Reference (2)) suggests that for thick shields (greater than 9 inches of concrete) 1 Mev may be better when calculations are done by the modified upper limit method (Reference(3)). The low energies of the radiation increase the complications of calculating from first principles because of air scattering effects. Figure 1 taken from Reference (1) p.403, gives values for the attenuation of residual gamma-radiation by various materials. It should be noted however that these curves (which are similar to those given in Figure 70 of Reference (4)), do not agree with the half-thickness values quoted in Table 9.35 page 402, of Reference (1). For example, the half-value thickness for concrete in the figure is read off as 4.5 inches, whereas in Table 9.35 it is given as 2.2 inches. In British Trials a figure of 2.3 inches was obtained, and the U.S. figure of 4.5 inches would therefore seem to be an error.

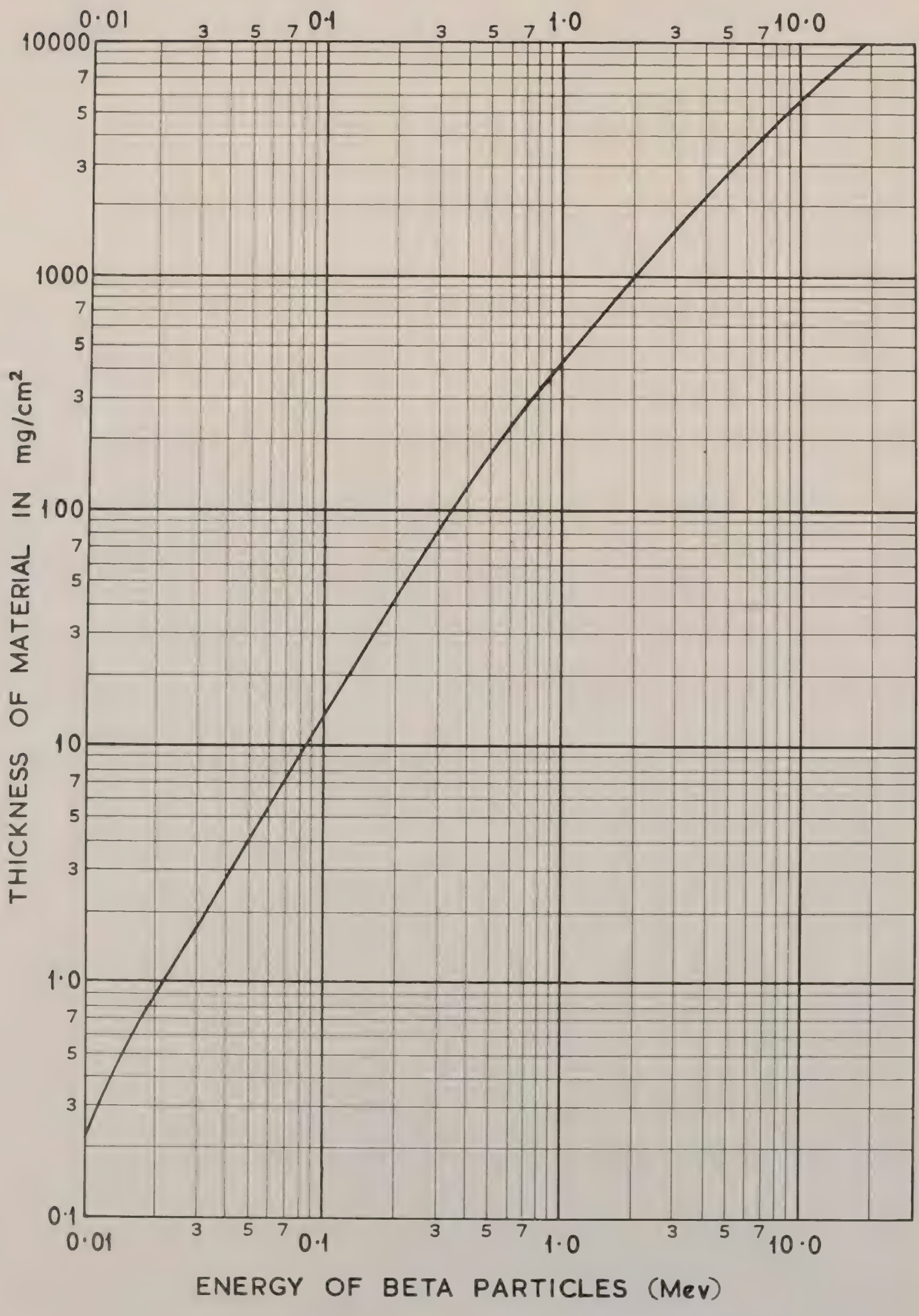
References

(1) The Effects of Nuclear Weapons, U.S. Atomic Energy Commission, 1957.

(2) Home Office Report CD/SA 62, 1955.

(3) Ministry of Supply, H.E.R. Report No. H13/51, 1951, "Tables for the Solution of Gamma-Ray Shielding Problems". (Restricted)

(4) Capabilities of Atomic Weapons, A.F.S.W.P. TM23-200 (1955) (Confidential/Atomic)



RANGES OF BETA PARTICLES

6.2. Shielding from Residual Beta-Radiation

The ranges of beta particles in matter are shown in Figure 1. Except in the early stages after the explosion (up to an hour or two), there are no radioactive explosion products emitting beta particles of more than about 3 Mev energy and most of them emit beta particles of 2 Mev or less. Study of Figure 1 shows that shielding against beta particles is quite an easy matter, and most ordinary structures (buildings, aircraft, vehicles, thick clothing, etc.) are enough to keep out all or most of the beta particles from explosion products. Of course, further protection may be needed against beta emitting substances which may drift or be blown through gaps in structures such as windows, ventilators, etc.

CHAPTER 6 - SHIELDING FROM RESIDUAL RADIATION

6.1 Introduction

A description of the nature and origin of the residual radiation from a nuclear weapon is given in Chapter 6 of Reference (1). An unclassified account will be found in Chapter 9, Reference (2).

The residual nuclear radiation is defined as that emitted after one minute from the instant of a nuclear explosion. This radiation arises mainly from the bomb residues, that is, from fission products and, to a lesser extent from the uranium and plutonium which have escaped fission. In addition, the residues will usually contain some radioactive isotopes formed as a result of neutron capture by the bomb materials. Another source of residual nuclear radiation is the activity induced by neutrons captured in various elements present in the earth, in the sea, or in substances which may be in the explosion environment (see Chapter 3, Section 3.2 for further details of neutron-induced activity).

In the case of an air burst, particularly when the ball of fire is well above the earth's surface, a fairly sharp distinction can be made between the initial and the residual nuclear radiation. The reason is that by the end of a minute essentially all the bomb residues, in the form of very small particles, will have risen to such a height that the nuclear radiations no longer reach the ground in significant amounts. Subsequently, the fine particles are widely dispersed in the atmosphere and descend to earth very slowly. With surface, and especially sub-surface explosions, the demarcation between initial and residual nuclear radiations is not as definite. Some of the radiations from the bomb residues will be within range of the earth's surface at all times, so that the initial and residual categories merge continuously into one another. For very deep underground and underwater bursts, the initial gamma rays and neutrons produced in the fission process may be ignored. Essentially, the only nuclear radiation of importance is that arising from the bomb residues. It can, consequently, be treated as consisting exclusively of the residual radiation. In a surface burst however, both initial and residual nuclear radiations must be taken into consideration.

The fission products constitute a very complex mixture of some 200 different isotopes of 35 elements. Most of these isotopes are radioactive, decaying by the emission of beta particles, frequently accompanied by gamma radiation. About 0.11 pounds of fission products are formed for each kiloton (or 110 lb. per megaton) of fission energy yield. The total radioactivity of the fission products initially is extremely large, but it falls off at a fairly rapid rate as a result of decay.

At one minute after a nuclear explosion the radioactivity from the 0.11 lb. of fission products from a 1-kiloton explosion is of the order of 10^5 megacuries.

Some indication of the rate at which the fission product radioactivity decreases with time may be obtained from the following approximate rule:-

> For every 7-fold increase in time after the explosion, the activity decreases by a factor of 10. For example, if the radiation intensity at one hour after the explosion is taken as a reference point, then at 7 hours after the explosion the intensity will have decreased to one-tenth; at 7 x 7 = 49 hours (or roughly two days) it will be one-hundredth; and at 7 x 7 x 7 = 343 hours (or roughly two weeks), the activity will be one-thousandth of that at one hour after the burst.

Another aspect of the rule is that at the end of one week (7 days), the radiation will be one-tenth of the value after one day. This rule is roughly applicable for about 200 days, after which time the radiation intensity decreases at a more rapid rate. (Reference should be made to Chapter 3, Section 3.2, for information on dose-rates from residual nuclear radiations.)

In the residual radiation period, there is no emission of neutrons, but once the debris reaches the ground there is a hazard from alpha and beta particles as well as from gamma radiation from the radioactive explosion products. Alpha particles, with a range of only a few centimetres in air, are hazardous only when taken into the body or when contamination is directly on the skin. Consequently, no special shielding need be prepared against alpha emitters; clothing which is effective against beta particles will be more than adequate to exclude alpha particles.

References

(1) Manual on the Effects of Atomic Weapons, A.W.R.E. (1955) (Secret/Atomic/U.K. Eyes Only)

(2) Effects of Nuclear Weapons, U.S.A.E.C., 1957.

5.2.7 Neutron shielding

Very little experimental information is available on the effectiveness of shields against the neutrons from a nuclear explosion. It is stated in Reference (1) that 10 inches of concrete will reduce the neutron dose by a factor of 10. Until more measurements have been made it is necessary to deduce the probable behaviour of shielding materials which might be used in practice from the available neutron cross section data.

In order to minimise the build-up factor a shield should be made of elements which have large sections for capture followed by emission of charged particles or radiation for the energies present in the incident neutron flux. In general it is not possible to make such a shield against a neutron source with an extended spectrum. All that can be done is to include a large proportion of light elements in the shield, so that, although the build-up factor will be large for thick shields, the energy of fast neutrons - and hence their lethality - will be considerably reduced at each collision. The average number of collisions in an element with relative efficiency η (hydrogen = 1) required to slow down a neutron from energy E_1 to energy E_2 is:

$$N_{E_2}^{E_1} = \eta \ln \frac{E_1}{E_2} \qquad (5.2.4)$$

The values of η for various common elements are shown in Table 1, together with the average number of collisions required to slow down 3 Mev neutrons to (a) thermal energies (N_{th}) where the probability of radiative capture (n, γ) is large, and (b) 10 Kev energy (N_{10} Kev) where the lethality ceases to decrease appreciably as the energy is further reduced.

TABLE 1

Relative Efficiencies of Various Elements as Absorbers of 3 Mev Neutrons

Element	H	B	C	N	O	Na	Si	Ca	Fe
η	1	0.18	0.155	0.132	0.120	0.085	0.070	0.049	0.035
N_{th}	18.6	103	120	141	155	219	266	380	530
$N_{10\ Kev}$	5.7	32	37	43	48	67	82	119	163

The average distance travelled by a neutron in a particular direction ($\overline{R}$) after N elastic collisions is given (in the case where scattering is isotropic in the centre of mass system) by:

$$\overline{R} = \sqrt{\frac{2N}{1 - \frac{2}{3A}}} . \lambda \qquad (5.2.5)$$

where λ is the mean free path and A is the atomic weight of the scattering nucleus. Combining equations (5.2.4) and (5.2.5) will give the average thickness of an absorber required to slow down neutrons from energy E_1 to E_2. The factor $(1 - \frac{2}{3A})^{-\frac{1}{2}}$ allows for the tendency a neutron has to be scattered forward in the "shield system" when scattering is isotropic in the centre of mass system. This tendency is much smaller than that shown by Compton

scattered gamma-rays (namely 50 per cent of scatter within 20° of the original direction at 3 Mev), and the factor $(1 - \frac{2}{3A})^{-\frac{1}{2}}$ can usually be ignored for all common elements except hydrogen.

The effect of absorbing neutrons in a few common materials is now considered.

(i) Air - This is considered as 80 per cent nitrogen and 20 per cent oxygen, the other elements present being neglected. N^{14} has three resonance peaks for the (n, p) process between 400 Kev and 1.6 Mev, and the average cross section for that reaction in this region is about 0.02b. The total cross section here is 2b. To slow down a 2 Mev neutron to 400 Kev by elastic collisions requires about 11 collisions, so that only about 10 per cent of the fast neutrons emitted by an atomic weapon will be absorbed by the (n, p) reaction in the atmosphere before they are slowed down. A neutron emitted from a weapon at 2 Mev would travel on an average about 2,300 ft. before being slowed down below 400 Kev. A 400 Kev neutron would be slowed down to near thermal velocities in about 1,700 ft. At thermal velocities N^{14} has a large cross section (1.8b) for (n, p); the (n, γ) cross section is 0.1b, so that approximately 5 per cent of the slow neutrons captured in N^{14} give rise to capture gamma-radiation. The spectrum of this radiation has been measured by Kinsey et al (Reference (2)); it includes strong components at about 11 and 5.5 Mev. The mean free paths of these gamma-rays in air are about 1,300 ft. and 1,000 ft. respectively. Siddons (Reference (3)), has calculated that the gamma-radiation from the (n, γ) process in N^{14} (in the atmosphere and in the high explosive contained in the weapon) probably accounts for about 20 per cent of the gamma-radiation at 3,000 ft. from a nominal weapon of low neutron output type. The (n, p) reactions in atmospheric N^{14} will reduce thermal neutrons to about 1 per cent in 1,000 ft.

The oxygen in the atmosphere plays a negligible part in capturing neutrons, although it helps in slowing them down.

(ii) Water - The hydrogen in water is very efficient in slowing down neutrons. A shield approximately 1 ft. thick would slow down to thermal velocities over 90 per cent of neutrons incident at 2 Mev, and so it may be assumed that such a shield would thermalise most of the neutrons from an atomic bomb incident upon it at any distance of interest.

Thermal neutrons are absorbed in hydrogen by radiative capture (cross section 0.33b), the capture radiation being a single line at 2.2 Mev. This is a much smaller amount of energy than is usually released in a (n, γ) process; the gamma-radiation normally released is of the order of 6 to 10 Mev. According to Cave (Reference (4)) the LD-50 of slow neutrons is about three times that of 2.2 Mev gamma quanta; therefore as these gamma-rays would be very little absorbed in water, a water shield - although decreasing the hazard from fast neutrons - would increase it from slow neutrons. The gamma hazard may be reduced by about 50 per cent by using a saturated solution of borax instead of water. Boron has a large cross section (750 b) for the (n, α) process with thermal neutrons, so that a large fraction of the neutrons are absorbed by this process, although the solubility of borax is only about 2 per cent at normal temperatures. The cost of borax in a saturated solution would be about 1d. per gallon.

In general, it will in any case be necessary to provide a gamma-ray shield against primary radiation from the weapon. If, in these circumstances,

the fast neutron flux is considered to be an additional hazard it may be screened off by a water shield outside the "gamma shelter". The water shield need not be very strong mechanically as most of the neutrons arrive before the shock wave.

(iii) Iron - The total cross section for iron has many resonance peaks in the range 2 Mev to 1 Kev. This suggests that inelastic scattering occurs. The average value of σ_t in this range is 3b. If the scattering were entirely elastic about 30 inches of steel would be required to slow down neutrons from 2 Mev to 1 Kev. As some of the scattering is probably inelastic, the actual thickness required will be less than 30 inches, although it will still be much greater than the 3-4 inch iron shields likely to be encountered in practice. The variation of σ_t with energy below 1 Kev indicates that most of the scattering is elastic and that about 12 inches of steel would be needed to slow down the 1 Kev neutrons to thermal energies.

At thermal energies the cross section for the (n, γ) process is 2.6b and the scattering cross section is 10b, so that most of the thermal neutrons incident on a sheet of steel more than three inches thick would be captured. The capture spectrum can be represented adequately as 1 gamma quantum at 8 Mev plus 0.7 gamma quantum at 5 Mev, for each neutron captured. The LD-50 of gamma radiation of approximately this energy is 2×10^{11} quanta/cm^2; therefore a flux of about 10^{11} thermal neutrons/cm^2 (which is less than 1/10 the LD-50) will give a LD-50 of gamma rays if captured in iron without gamma-ray attenuation. The mean free path of such gamma-rays in iron is 4.2 cm, and thus the self-absorption in a 3-inch shield would reduce the gamma-ray dose by about 50 per cent. Another factor of 2 is gained if the neutrons are incident on only one face of the iron shield (assumed to be an extended plane) since the gamma-rays are emitted isotropically. Even so, it seems that the type of iron shield likely to be encountered offers very little protection against fast neutrons and increases the hazard from slow neutrons.

(iv) Concrete - A concrete containing gravel (mostly silica) as the aggregate, and mixed according to the common recipe (1 part cement, 2 parts sand, 4 parts aggregate, water to cement ratio 0.5, all ratios by volume) will have a density of about 2.3 gm/cc and will contain the following numbers of atoms of the constituent elements per cc:

H	O	Si	Ca	
1.5×10^{22}	4.6×10^{22}	1.8×10^{22}	0.25×10^{22}	atoms/cc

If all collisions were elastic then 1 cm of concrete would be equivalent to about 0.4 cm of water for slowing down neutrons. This would indicate that a concrete shield about 2 ft. 6 ins. thick would be required to thermalise the neutrons from a nuclear weapon. Since there are probably some inelastic collisions with silicon the actual shield required may be less than this.

About 70 per cent of the thermal neutrons absorbed in concrete are captured by the (n, γ) process. With H^1, one 2.2 Mev gamma quantum is emitted for each neutron captured; the remainder are absorbed in the Si and Ca, emitting on the average two 4.0 Mev quanta. Hence the absorption of 3.5×10^{11} thermal neutrons in concrete would result in a LD-50 of gamma-radiation if the gamma-rays were not absorbed. The mean free path of the capture gamma-rays is about five inches in concrete so that the hazard from gamma-rays emitted from a concrete shield thicker than about 12 inches would be less than that from the thermal neutrons incident upon it.

The efficiency of concrete as a neutron absorber can be increased by increasing its hydrogen content, but unfortunately there are not many hydrogen compounds available which would be suitable for use as part of the aggregate. Gugelot and White (Reference (5)), found that the shielding properties could be improved by including limonite ore ($2Fe_2O_3\ 3H_2O$) in the aggregate. They were studying the absorption of neutrons produced by bombarding a beryllium target with 16 Mev protons; such neutrons have a higher effective energy than those from a nuclear weapon, but the results may be used as a guide. Various other improved mixes were tried and it was found that when mixing and transport costs were taken into account, a given attenuation could be obtained more cheaply by using a shield of standard concrete than with a thinner shield of improved concrete. These special mixes are only attractive when space or weight are at a premium.

References

(1) The Effects of Nuclear Weapons, U.S.A.E.C. 1957, p.367.

(2) B. B. Kinsey et al, Canadian Journal of Physics, Vol. 29, p.1 (1951)

(3) A.W.R.E. Report No. E5/54 - "Gamma Emission Resulting from the Radiative Capture of Neutrons by Nitrogen during an Atomic Explosion". (Secret/Atomic/U.K.Eyes Only).

(4) L. Cave, British Journal of Radiology, Vol. 27, p.273 (1954)

(5) P. C. Gugelot and M. G. White, Journal of Applied Physics, Vol. 21, p.369 (1950).

5.2.6 Neutron absorption processes

A neutron in a narrow parallel beam of neutrons passing through an absorber may be removed from the beam by elastic scattering or by capture. If σ_t is the cross section (in cm^2) of a nucleus for the removal of a neutron from the beam in any way, and N is the number of nuclei/cm^3, the number of neutrons (I_x) left in the beam after penetrating a distance x cm, is:

$$I_x = I_o e^{-N\sigma_t x} = I_o e^{-\mu_t x} = I_o e^{-\frac{x}{\lambda}} \qquad (5.2.2)$$

where I_o = number of neutrons in the beam at distance x = o

μ_t = $N\sigma_t$, is the narrow beam absorption coefficient (cm^{-1})

$\lambda = \frac{1}{\mu}$, is the mean free path (cm).

Nuclear radii are of the order of 10^{-13} to 10^{-12} cm, and it is therefore convenient to express σ_t (which geometrically we would expect to be approximately Πr^2) in barns, where 1 barn = 1b = 10^{-24} cm^2.

The situation described above corresponds to narrow beam absorption; in practice we usually have to deal with situations corresponding to broad beam absorption, where neutrons scattered out of the beam but not absorbed, must also be considered. These can be formally allowed for (as in the gamma-ray case) by introducing a build-up factor, B [x, g(E), M] which will be a function of the distance penetrated (x), the energy distribution of the incident neutrons g(E), and the composition of the absorber (M). In view of the complex way in which the probability of neutron absorption processes depend on the energy of the neutron and the nature of the absorber, it is not generally feasible to deduce the build-up factor analytically. Qualitatively it can be seen that shields composed of elements in which elastic and inelastic scattering predominate will have large build-up factors, whereas any other type of interaction will tend to reduce it. In this connection it should be noted that radiative capture, although it reduces the neutron flux, results in gamma-rays which in many cases are more dangerous than the neutrons producing them.

Neutron cross sections do not show a regular variation with neutron energy and atomic number of the target, but some general trends are observable:

(a) The elastic scattering cross section increases with atomic weight (A) approximately as $A^{\frac{2}{3}}$ (as would be expected if nuclear matter had a constant density), and decreases with increasing energy. The importance of this process for shielding purposes is that it results in a slowing down of fast neutrons. For this to occur with a small number of collisions, A should be small (see Equation 5.2.1.).

(b) The cross section for any other process depends on two factors:-

(i) σ_c, the cross section for compound nucleus formation;

(ii) P_i, the probability that the compound nucleus will decay by process i.

Hence σ_i, the cross section for the process i, is $\sigma_i = \sigma_c . P_i$

The variation of σ_c with energy actually shows many resonance peaks, but if the resonances are averaged out its behaviour at energies less than 0.5 Mev is described fairly well by the relation:

$$\sigma_c \approx \frac{0.5}{E^{\frac{1}{2}}} \text{ barns (E in Mev)} \qquad (5.2.3)$$

For higher energies it is necessary to add to this simple equation a term varying with the atomic weight of the target nucleus as $A^{2/3}$. The equation shows that the capture cross section increases with decreasing energy, which explains why fast neutrons must generally be slowed down in a shield before they can be efficiently captured.

The relative probabilities of the various modes of decay of the compound nucleus are governed by characteristics of the nuclei close to it in mass number. They do not show any regularities, except that at low energies the only possible mode of decay is usually gamma emission.

Most of the information available on neutron cross sections is collected in Reference (1), in the form of a table of thermal neutron cross sections and graphs of σ as a function of energy for each isotope investigated. Reference (2) gives a summary of information on fission neutron reaction cross sections.

References

(1) Hughes and Harvey, Neutron Cross-Sections, USAEC Report BNL-325 (1955)

(2) Nucleonics Vol. 13 (No. 11) p.67, Data Sheet No. 8.
Neutron Physics, Fission Neutron Reaction Cross Sections.

5.2.4 Lethal dose of neutrons

The lethality of any radiation is described in terms of the dose which would be responsible for the death of 50 per cent of the exposed population. This dose is referred to as the 50 per cent lethal dose, or LD-50.

The LD-50 of neutrons for man depends on the energy of the neutrons, but there is some doubt as to the extent of this dependence. In Reference (1) it is stated that the generally accepted values of the lethal doses of slow (less than 0.2 ev) and fast (greater than 3 Mev) neutrons are 5×10^{11} neutrons/cm^2 and 10^{11} neutrons/cm^2 respectively. Marley (Reference (2)) takes 4×10^{11} neutrons/cm^2 and 10^{10} neutrons/cm^2 as the LD-50s for these two groups. Cave (Reference (3)), assuming that the lethal dose creates in the body an amount of ionisation biologically equivalent to that created by the lethal dose of gamma radiation (400r), arrives at the dependence of lethal dose on energy shown in column 2 of Table 1. Account is taken, both of the high energy protons from neutron collisions, and of the capture gammas. These values are based on a relative biological efficiency (r.b.e.) for fast protons of 6.5, i.e. it is considered that a given amount of energy released in tissue by fast protons is biologically equivalent to 6.5 times that amount of energy released by gamma-rays. It is now thought that this is too high for acute exposures and values between 1.4 (Reference (4)) and 0.5 (Reference (5)) have been suggested for this case. Column 3 of Table 1 results from Cave's data when 1.3 is taken as the r.b.e. of fast protons.

TABLE 1

Relation between Neutron Energy and Lethal Dose

Neutron Energy	LD-50 (Neutrons/cm^2) (Proton r.b.e. = 6.5)	LD-50 (Neutrons/cm^2) (Proton r.b.e. = 1.3)
Thermal	1.6×10^{12}	1.6×10^{12}
1 Kev	1.8×10^{12}	1.8×10^{12}
3 Kev	1.7×10^{12}	1.8×10^{12}
10 Kev	1.4×10^{12}	1.6×10^{12}
30 Kev	9.2×10^{11}	1.5×10^{12}
100 Kev	4.1×10^{11}	1.1×10^{12}
300 Kev	1.6×10^{11}	5.9×10^{11}
1.0 Mev	5.0×10^{10}	2.2×10^{11}
3.0 Mev	1.6×10^{10}	8.2×10^{10}

References

(1) The Effects of Atomic Weapons, U.S.A.E.C., 1950

(2) A.E.R.E. Report No. HP/R.422

(3) L. Cave, British Journal of Radiology, Vol. 27, page 273 (1954)

(4) The Effects of Nuclear Weapons P.363, U.S.A.E.C., 1957

(5) Radiological Hazard Evaluation, U.S.N.R.D.L., 1957.

5.2.3 Angular Distribution at the Target

Very few measurements of the angular distribution of neutrons at the target have been reported. Western (Reference (1)) found that a thick wall 18 feet long by 7½ feet high reduced the fast neutron flux to between 13% and 23%, showing that at least this part of the flux is due to scattered neutrons.

It is generally considered (e.g. see Reference (2)) that the distribution of slow neutrons is isotropic at distances from the detonation greater than 1,000 feet, as such neutrons have been scattered many times. The fast neutron angular distribution will, however, show a tendency for neutrons in this group to be incident from the direction of the explosion.

The angular distribution of neutrons at the target is considered by Mehl in Reference (3). At 900 metres from a nuclear test explosion less than one per cent of the flux in the energy interval between 0.7 and 1.5 Mev was from unscattered neutrons, yet the distribution was peaked quite strongly in the outward direction. As the neutrons were moderated to lower energies the distribution became more nearly isotropic, but it still peaked outwards. Preliminary results from this test are given in Table I.

TABLE 1

Angular Distribution of Neutron Flux at 900m from Weapon

θ°	Neutron Energy Band		
	200 eV/0.1 Mev	0.1/0.7 Mev	0.7/1.5 Mev
90° - 60°	0.85	0.38	0.18
60° - 30°	0.75	0.30	0.07
30° - -10°	0.60	0.20	0.03
-10° - 660°	0.52	0.16	0.02
-60° - -90°	0.45	0.14	0.015

θ = Angle from vertical in plane including the weapon, measured positive on side away from the weapon.

References

(1) Attenuation and Scattering of Initial Nuclear Radiation, Home Office Report CD/SA.85. (Confidential)

(2) The Effects of Nuclear Weapons, page 368, U.S.A.E.C., 1957.

(3) Scaling Neutron Flux with Altitude, C.R. Mehl. Tripartite Conference on Effects of Atomic Weapons (1957).

5.2.5 Lethal range of neutrons

The lethal range of neutrons is the distance at which the neutron dose has fallen to the LD-50. It can be assessed, for unshielded persons, from the neutron dose/distance relationship (Figures 8 and 9 of Sections 3.1, Chapter 3), if the power of the weapon and its relative neutron yield are known. Alternatively it can be deduced from the neutron flux/distance relationship if the value of the r.b.e. appropriate to the fast protons produced in tissue is also known.

Table 1 gives the lethal ranges obtained from these curves in conjunction with Table 1 of Section 5.2.4, for a number of yields. It also gives the lethal range of the gamma radiation for comparison. The Table shows that where neutron flux measurements only are available for a weapon the lethal range can be estimated from these measurements assuming a proton r.b.e. value of 1.3. It will be seen that even for high neutron yield weapons the gamma radiation lethal range is greater than that of the neutrons for yields in excess of about 20 KT.

TABLE 1

Lethal Ranges for Neutron and Gamma Radiation (Feet)

Weapon Yield KT	Low Neutron yield weapons			High neutron yield weapons			Gamma Rays
	Dose Data	Flux Data Proton r.b.e.		Dose Data	Flux Data Proton r.b.e.		
		1.3	6.5		1.3	6.5	
1.0	1230	1290	1710	2460	2400	2970	2070
10	2100	2130	2670	3600	3480	4140	3390
100	3150	3150	3750	4830	4680	5430	5280
1000	4290	4290	5040	6210	6000	6750	7950

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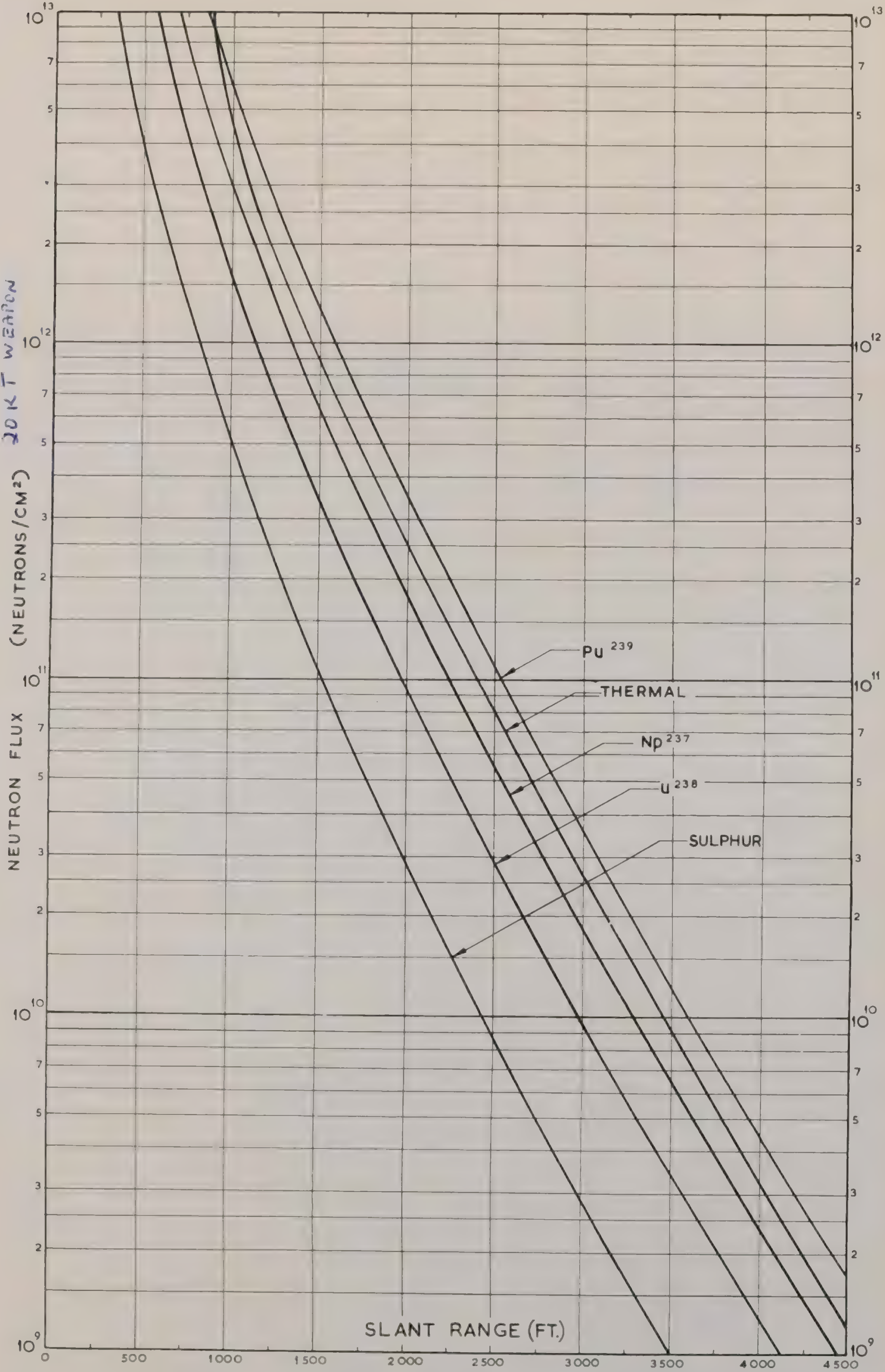

FAST AND THERMAL NEUTRON FLUXES
AS A FUNCTION OF SLANT RANGE

CHAPTER 8 - DECONTAMINATION

8.1 General Considerations

8.1.1 The nature of the problem

The radioactive contamination produced by the explosion of a nuclear weapon cannot be destroyed, since radioactivity is a property of the atomic nucleus. The hazard associated with this contamination may be dealt with in three ways. Firstly, by disposing of the whole of the contaminated material by deep burial in the ground or at sea; secondly, by keeping it at a safe distance until the radioactivity has decayed to a tolerable level; and thirdly, by removing the contamination from the material. The third method (i.e. decontamination) therefore consists of removing the contamination from surfaces where it is dangerous and disposing of it where it can do no harm.

The method adopted in any particular case will depend on a number of factors. These include, with reference to a specific contaminated object or area, the initial and maximum tolerable intensities of the radiation, decay rate, cost or disposal and replacement, strategic value, and the work to be done in decontamination. Large structures could not easily be disposed of, but decontamination could be undertaken after the activity had decayed sufficiently to permit the work. In the case of smaller objects having high activity, burial might be more economical. In many instances it might be an advantage merely to isolate the object or structure and allow the activity to decay. Beta and gamma radiation emitted by contamination arising from a fission explosion will decay approximately in accordance with the equation:-

$$I_t = I_o . t^{-1.2} \qquad (8.1)$$

where I_o and I_t are the radiation intensities at unit time and after time t respectively.

In Reference (1), which records observations made at Operation Mosiac, it is noted that the decay of residual gamma activity corresponded to a slope of $t^{-1.7}$. A report by Dunning (Reference (2)) on observations made in the Marshall Islands following a U.S. nuclear test, notes that during the first ten days after detonation the decrease in activity corresponded to a slope of $t^{-1.2}$. From 25 days up to 1 year the slope was approximately $t^{-1.7}$.

References

(1) A.W.R.E. Report No. T.21/57

(2) G. M. Dunning "Criteria for Evaluating Gamma Radiation Exposures from Fallout following Nuclear Detonations". Radiology, Vol. 66, No. 4, pp.585-94, April, 1956.

8.1.2 Origins of Contamination

Radioactive contamination may be caused by the fission and other active products from a nuclear explosion (reference Chapter 7), by neutron-induced activity in soil and water (reference Chapter 3.2), and from any fissile material remaining after the explosion.

The fission products will be responsible for the emission of beta and gamma radiation, and the unused fissile material for the production of alpha rays. Owing to the long half-life of the fissile material and its dispersion by the explosion, the resultant alpha radiation will usually be negligible, although in the case of a very inefficient explosion (a 'fizzle'), an appreciable quantity of fissile material will be distributed over a limited area, with consequent increased danger from alpha radiation.

Contamination from fission products and fissile material will be confined to surfaces, whereas neutron-induced activity may be produced at depths as great as several feet below surfaces. Some of the more important radio-isotopes produced in this way are listed in Table 1. Further details of neutron-induced activity may be obtained from References (1) and (2).

Table 1 - Neutron Induced Radio-Elements

Element	Radio-Element	Half-life of Radio-element	Types of Radiation
Aluminium	Al 28	2.3 min.	β, γ
Chlorine	Cl 38	37 min.	β, γ
Copper	Cu 64	12.8 hr.	β, β^{+},γ
Iron	Fe 59	45 days	β, γ
Magnesium	Mg 27	9.6 min.	β, γ
Manganese	Mn 56	2.6 hr.	β, γ
Nitrogen	C 14	5,600 years	β
Sodium	Na 24	15 hr.	β, γ
Zinc	Zn 65	245 days	$\beta+$, γ

These induced radio-isotopes will be present in depth and decontamination will not be possible. However, owing to the limited range of the neutrons (reference Chapter 3.2) this form of activation will seldom extend to material which was more than a few hundred yards from the point of the explosion at the instant of burst.

References

(1) D.A.W.Plans Note No.15 - Neutron-Induced Radioactivity

(2) A.W.R.E. Report T35/58.

8.1.3. Effect of type of burst and terrain

In the case of low overland and air bursts the fission products and unused fissile material appear in the form of oxides and ntirides, most of which are carried up with the cloud of debris. The local fallout from such explosions is a dry, inert dust highly resistant to chemical treatment. On the other hand, an underwater explosion produces a chemically reactive form of fission product which may be present in droplets of mist or as an aqueous mud slurry. These two types of contamination - 'reactive' and 'inert' - are likely to respond differently in decontamination operations, but in many cases however, the fallout will be of an intermediate type. For example, an air burst on a cloudy or rainy day may produce more reactive contamination than on a clear bright day. The nature of the contamination likely to arise from various types of burst is summarised in Table 1, which is taken from Reference (1). The advent of dew or rain is likely to blur these distinctions.

TABLE 1

Contamination Resulting from Various Types of Burst

Type of Burst	Degree of Contamination	Reactivity
High Air	Slight	Inert
Low Overland	Moderate	Inert
Low Overwater	Moderate to heavy	Fairly reactive
Underwater	Heavy (base surge cloud)	Reactive
Underground	Probably heavy to very heavy	Mainly inert
Rain precipitated contamination	Variable	Mainly reactive

The removal of reactive contamination may be assisted by chemical means if the chemical nature of the contaminant is known. The percentages of various elements in a fission product mixture are continuously changing, but the basic alkaline earths, rare earths, and other metallic elements, predominate. Two exceptions are iodine and tellurium, which are acidic in character. The chemical nature of the elements contained in inert contamination, which settles as dust, is not important in decontamination operations in the field.

References

(1) A.W.R.E. Report No. 0-49/55 - %A Guide to Radiological Decontamination after a Nuclear Explosion or Radiological Attack". (Official Use Only)

8.2. The Effect of Surface Conditions

The fallout from a nuclear explosion will settle in the form of particles of various sizes (reference Chapter 7), and the coarser particles will simply lie on the surfaces on which they come to rest, being removable by sweeping or suction. Finer dust particles may be attached to the surface by various means, such as adhesion by grease, or trapping by the pores in a rough surface.

Attachment by a form of ion-exchange is likely in all cases where the contaminant is soluble and may also occur in the case of surfaces which have available acid groups. These groups would be provided by organic surfaces such as paint, plastics and textiles, and also by glass. Ion-exchange between the acid groups and basic materials present in soluble or reactive contamination gives rise to strong adhesive forces. Chemical exchange may also occur on metal surfaces.

The results of tests to examine the influence of surface roughness, hardness and cleanliness on the contamination - decontamination behaviour of various materials (e.g. glass, tiles, metals, plastics, paints, etc.) have been reported in Reference (1).

The tests involved both a surface and underground burst, and the conclusions reached may be summarised as follows:-

(i) Surface roughness had no clearly defined effect on contaminability. Surface roughness did affect decontaminability by factors of 6-10 (for residual activity), the rough surfaces retaining more contamination than the smooth.

(ii) From data obtained with polyisobutylene it appeared that soft surfaces were contaminated to a greater degree than hard surfaces, and retained two to three times more activity (absolute) after decontamination, than hard surfaces.

(iii) Artificially soiled surfaces were more easily contaminated than clean surfaces by a factor of 2 to 7.5, but were decontaminated as well as, or better than clean surfaces.

(iv) Navy grey paint was from 1.5 to 12 times as contaminable as bare aluminium, glass, and chromium-nickel steel, but all these materials were readily decontaminated.

Results from further tests reported in Reference (1) show that contamination on horizontal surfaces was greater than on non-horizontal surfaces by factors up to 30 to 40. Vertical surfaces retained smaller particle sizes than inclined or horizontal surfaces. Very extensive measurements are reported in detail, and include a wide variety of surfaces and treatments.

References

(1) U.S. Armed Forces Special Weapons Project Report No. WT-400 "Operation Jangle".

Project 6.2 "Protection and Decontamination of Land Targets and Vehicles". (Secret)

8.3. General Decontamination Methods

8.3.1. Introduction

The method selected for decontamination will depend on the type of contamination, the extent of removal desired, the nature of the surface and the size of the object.

The methods available for the decontamination of objects, structures, roads, etc., may be considered under four headings:-

(i) Sweeping and vacuum cleaning.

(ii) Detergency

(iii) Chemical treatment

(iv) Surface removal.

In the case of land reclamation, special techniques requiring earth-moving equipment may be employed.

In all of these methods the techniques must be arranged to give the maximum possible protection to the operators, who will require adequate protective clothing, and suitable instruments for the measurement of radiation levels.

Since the object of decontamination work is to remove and confine the activity, an essential consideration is the disposal of contaminated waste. This must be conveyed or otherwise removed to a location where it does not constitute a danger.

8.3.2. Sweeping and vacuum cleaning

These are dry methods and in general tend to be more hazardous than wet processes. They are of use however, where the contaminant is mainly of an inert dusty nature. Vacuum cleaning is safer and more efficient than brushing, but the filters in commercial equipment do not ensure complete retention of radioactive dust.

A comparison between vacuum technique and high pressure hosing is given in Reference (1), and states that decontamination by vacuuming is relatively inefficient. Vacuuming at a decontamination rate of 40 sq.ft. per equipment-hour left a high residual contamination ranging from 9 to 84%. A high pressure water stream with detergent additive, on the other hand, cleaned a rough roof surface, slag or gravel finished, at a rate of approximately 600 sq.ft. per equipment-hour and left an average residual contamination of less than 2%.

It should be noted however that much will depend on the precise conditions, particularly particle size of the dust, and in many cases vacuum cleaning can be very efficient.

8.3.3. Detergency

This method consists of wet treatment of the surface with a detergent solution and is a relatively cheap and safe process. It is particularly effective in cleaning inert dusty contamination from smooth surfaces, but is less useful on surfaces where adsorption has occurred. Reactive contamination will respond to the use of a suitable detergent, and the nature of the detergent is of greater importance in this case.

The hazards from ingestion and inhalation of loose dust from a surface are considerably reduced by washing or spraying down the surface with detergent solution. In cases of more persistent contamination scrubbing or brushing will give improved results. The composition and application of various detergent solutions are given in Section 8.8, and the techniques for their use in Section 8.9.

8.3.4. Chemical treatment (complexing)

This treatment is carried out as a wet process using a solution of a "complexing" agent in conjunction with detergent action. The method is particularly suitable for removing reactive contamination from textiles, from smooth or thin porous surfaces, and from surfaces in general which do not respond satisfactorily to straight detergent. The complexing agent is a normally non-corrosive substance which will convert the contamination into a chemical form which is no longer retained by the surface. An example of such a substance is ethylene-diamine-tetra-acetic acid (EDTA). Details of this method and its application may be obtained from References (2) and (3).

8.3.5. Surface removal

This method may be carried out by a large variety of techniques, most of which are laborious but eventually very effective. Complete decontamination is usually possible.

Abrasive compositions are best applied under wet conditions together with the detergent and other additives. The composition of an efficient scouring paste is given in Section 8.8. Suitable chemical agents may be selected for specific types of surface, for example, acids for metal cleaning, and alkaline solution or suitable solvents for paint stripping.

Flame decontamination may also be considered as a surface removal technique. Reference (1) gives a description of a flame decontaminating unit (USNRDL Flaminator) incorporating a burner, a surface removal tool, and a vacuum pick-up system, which was tested on wood, asphalt and concrete surfaces contaminated by an underground burst atomic weapon. No apparent hazard is involved in the maintenance of the Flaminator, but during operations the operator must be protected by an efficient respirator.

8.3.6. Land reclamation

Since the contamination is mainly held in the superficial layer of soil, the radiation field from a contaminated natural land area may be reduced for limited sectors by standard methods of earth movement such as ploughing, harrowing, scraping and filling. The use of such surface techniques is described in Reference (1). It is stated that time, man-power and equipment requirements do not differ significantly from those that would apply in the absence of radioactive contamination. Tests were made following a surface burst, and the test area was plane and free from gulleys and surface irregularities, and covered to about 10% by sage brush from one to three feet high. The soil was a non-compacted, non-cohesive silty sand weighing about 150 lb./cu.ft. The moisture content, owing to rainfall before the weapon burst, was about 20% to a depth of 6 inches. It is stated that the radiation fields were reduced 70 - 90% through the use of standard earth-moving procedures and equipment. In the scraping operations, it is unnecessary to haul the spoil any further than the boundaries of the area to be treated, and this material should be spread in a layer two to four inches deep.

Owing to the shielding afforded by the equipment the operators receive from 60 - 70% less readiation dosage than unshielded personnel working in the same area at the same time. Internal hazards due to the presence of airborne activity during operations can be minimised by the use of standard protective clothing and full-face respirator. Contamination of operating equipment does not constitute a serious hazard. In general, equipment will pick up a maximum of 10% of the level of the field in which it operates. Decontamination to acceptable tolerance levels can be accomplished adequately with high pressure hoses.

Another method also described in Reference (1) is designed to give protection to personnel traversing or occupying a radioactively contaminated region, by interposing earth barriers between the radiation source and the area occupied. It was found that an earth wall 4.5 ft. high, on each side of a 30 ft. wide roadway, reduced the radiation field in the roadway by a factor of about 3.5.

The radiation intensity at the bottom of a fox hole and a trench was found to be less than that at 3 ft. above the ground by a factor of about 20.

A circular cleared area 180 ft. in diameter afforded a radiation reduction of a factor of 5, measured 3 ft. above the centre. It was determined that increases in the diameter of the clearing beyond 200 ft. did not afford any significantly greater reduction at the centre.

In comparing barrier and surface techniques, it was found that for a given amount of time, and using identical equipment, surface clearing yielded a greater maximum reduction in the radiation field (by a factor of 1.5) and produced approximately four times the working area produced by the barrier technique.

The recontamination of treated areas through wind action is relatively unpredictable on the basis of present knowledge.

References

(1) U.S. Armed Forces Special Weapons Project, Report No. WT-400, Operation 'Jangle'. Project 6.2 "Protection and Decontamination of Land Targets and Vehicles. (Secret)

(2) A.W.R.E. Report No. T22/57, Operation Buffalo, Decontamination Group Report, Parts 1-4. (Confidential)

(3) A.W.R.E. Report No. T63/57. The Handling, Servicing and Decontamination of Radioactive Aircraft. (Official Use Only)

8.4 Decontamination of Vehicles and Aircraft

Vehicles. Information regarding the contamination and decontamination of military vehicles at an atomic weapon test has been obtained from Reference (1). No difficult problems of decontamination were experienced, although vehicles operated in areas contaminated at levels up to 50r/hour, and included Weasels which operated on the lip of a surface burst crater $2\frac{1}{2}$ hours after the time of burst. These Weasels were monitored approximately 24 hours after the burst time and had a general level of contamination of 30 mr/hour. Their treads gave readings of 70 mr/hour, and the levels of activity in the personnel compartments were 10 mr/hour.

Tanks which were operated in the same areas one day after the surface explosion displayed activity levels two or three times background.

High levels of intensity (up to 13r/hour) were noted in the beds of vehicles used for transporting contaminated material from radioactive areas.

Soil properties influenced the degree of contamination, and it is believed that fine dry soil of the type present in the test area lessened the decontamination problem. Under wet conditions greater contamination of the vehicle occurs, although the dust hazard to the operators and the upper surface contamination of the vehicle is reduced.

It is recommended that vehicle decontamination procedures be based on the urgency of the situation and that the following emergency methods may be used by the vehicle operator.

(i) Dry sweeping or brushing of the vehicle, paying particular attention to the removal of as much dirt as possible from the cab.

(ii) Wiping with wet rags.

(iii) Brush scrubbing with water, or soap and water; if plentiful water is available more thorough decontamination could be achieved by hosing down with water and scrubbing.

(iv) Greasy or oily areas may be cleaned by petrol applied on brushes or rags, (water is ineffective in this case).

A detailed account of the decontamination of vehicles (3-ton trucks, 1-ton trucks, Landrovers, armoured scout cars, etc.) used at Operation Buffalo is given in Reference (2). Steam cleaning was found to be the quickest and most satisfactory method for extensive and greasy areas, e.g. engines, chassis and vehicle surfaces generally. A disadvantage in the use of steam was the lack of both control and visibility. High pressure hosing was a little slower, but more economical.

Aircraft. The decontamination of aircraft used at two British trials is reported in Reference (3) (Operation Mosaic) and Reference (2), (Operation Buffalo). It is noted in the latter reference that the contaminant, in contrast to ground fallout, appeared to be largely ionic and therefore required the use of complexing agents or barrier films for efficient removal. The initial levels were relatively uniform, suggesting absorption contamination mechanism rather than impaction. Reference (2) gives much detailed information on decontamination materials, procedures and man-power requirements for both vehicles and aircraft. A manual dealing exclusively with the handling, servicing and decontamination of radioactive aircraft

has been prepared (Reference (4)).

The effectiveness of various methods and cleaning compounds for the decontamination of aircraft contaminated by flying through an atomic cloud were investigated during the U.S. Operation Snapper, and are reported in Reference (5). Methods using brushing techniques were generally more effective than those not involving brushes. A solvent emulsion grease cleaning compound ("gunk" USAF Spec. 20015) was one of the most effective cleaning agents. Tests were made to determine the influence of surface condition, i.e. oiled, cleaned and polished, on contaminability. Surfaces coated with a light film of oil contaminated to a level six times as high as a clean clad aluminium surface. Polished surfaces became only half as contaminated as the clean clad aluminium.

Ultra-violet light and fluorescent zinc sulphide were employed to determine the possible contamination distribution throughout the interior of jet aircraft. Stepwise decontamination showed that the cockpit dose-rate could be reduced by approximately 60 per cent by decontaminating the air intake duct, tail pipe, and exterior surfaces. The remaining 40 per cent was contributed by the engine, residual contamination and contaminated places not accessible for decontamination. It should be noted however, that the effect of various measures on cockpit dose-rate will vary with the particular aircraft, and especially with the distance between the engines and the cockpit. Further, the validity of using zinc sulphide as a simulant is not established.

Regarding aircraft in general, a distinction should be made between aircraft contaminated on the ground and those contaminated in the air. Barrier films are effective in countering airborne contamination, by preventing contact between the soluble contaminant and the paint surface, (see References (2) and (4) for details).

References

(1) U.S. Armed Forces Special Weapons Project, Report No. WT-400, Operation Jangle. Project 6.2 - "Protection and Decontamination of Land Targets and Vehicles". (Secret)

(2) A.W.R.E. Report No. T22/57. Operation Buffalo, Decontamination Group Reports, Parts 1-4. (Confidential)

(3) A.W.R.E. Report No. T33/57. Operation Mosaic, Aircraft Decontamination (Confidential)

(4) A.W.R.E. Report No. T63/57. The Handling, Servicing, and Decontamination of Radioactive Aircraft. (Official Use Only)

(5) U.S. Armed Forces Special Weapons Project, Report WT-535 (March, 1953) Operation Snapper, Project 6.5 "Decontamination of Aircraft". (Confidential/Atomic)

8.5. Decontamination of Food and Water

Food protected by cans, dust-proof wrappings, or other effective measures should undergo little or no contamination from fallout. There is no practical means of salvaging food which has become radioactively contaminated.

Water supplies might be contaminated by radioactive dust falling on a reservoir or other source of supply. In surface waters the radioactive contaminants will tend to be adsorbed by suspended and colloidal matter and will eventually settle or be deposited on any available surface. Material carried out from a reservoir is likely to be removed by the normal water purification process, which usually includes sedimentation and filtration stages. Because of the absorptive properties of soil, underground sources of water such as springs and wells would usually be safe from contamination.

If a river or reservoir is seriously contaminated, and the water is not subjected to any purification processes, the water may be unfit for consumption for several days. Careful examination of the supply would be necessary, and it must be remembered that in this connection alpha and beta activity, as well as gamma, are very important.

Contaminated water may be purified by the use of cationic and anionic exchange columns (de-mineralisers) and also by distillation. The mere boiling of water contaminated with radioactivity is of no value. The accepted safe tolerance level for water containing fission products is 4×10^{-6} microcuries/cc. Acceptable emergency activities for drinking water are given in Table 2, Section 3.3 of Chapter 3.

A method of removing dissolved fission products from potential drinking water supplies in the field has been developed at the Water Pollution Research Laboratory (DSIR). Reference (1) deals with field trials of a 1/20 scale apparatus that was used at Operation Buffalo. The apparatus worked effectively, with the exception of the removal of radioactive iodine.

Factors affecting the usability of contaminated foodstuffs are discussed in Reference (2), of which further details are given in Chapter 3, Section 3.3.

References

(1) A.W.R.E. Report No. T4/57 (Confidential) - "The Decontamination of radioactively contaminated drinking water in the field".

(2) A.W.R.E. Report No. 0-34/56 (Official use only) - "Ingestion of Food Contaminated by Atomic Explosions".

8.6. Protective Measures

The best protection against radioactive contamination is to use surfaces which are resistant to such contamination or from which the activity may be easily removed. Large-scale measures of this kind would hardly be feasible, but some action could be taken where there is a high probability of contamination, and anti-contamination measures are desirable.

Certain materials, such as polythene, P.V.C. and paper of suitable strength, may be used for form thin protective surface layers on various articles.

Structural materials such as brick, concrete, and wood are a special problem, since the complete decontamination of porous materials is almost impossible. The best means of protection is a good coating of a sealing agent such as paint. In designing structures, the avoidance of cracks, concavities, inaccessible spaces and poor drainage, would facilitate decontamination operations.

A means of protection which could be used where large quantities of water are available is the pre-wetting of exposed surfaces. For example, by saturating the paintwork on a ship with water, the uptake of reactive contamination from mist or spray is greatly reduced, and the surface may easily be decontaminated by further washing with water.

Barrier paints are particularly suitable for the protection of aircraft surfaces. The requirements for a barrier paint or film include ease of application, ease of removal, durability and weather resistance. The satisfactory use of barrier paints at British Trials is reported in Reference (1).

A further point is that where vehicles and the like are to enter an active area all non-essential accessories should be removed to minimise the work of decontamination. Canvas canopies on trucks are an example.

References

(1) A.W.R.E. Report No. T22/57, Operation Buffalo, Decontamination Group Report, Parts 1-4. (Confidential)

8.7. Waste Disposal

The disposal of contaminated waste is a problem which must be overcome in any decontamination work. The exact method used in any particular case will be determined largely by the circumstances, but ultimately disposal can be achieved only by dilution or storage.

The disadvantage of hosing down (except at sea) is that large volumes of water must be diposed of.

All highly contaminated waste, whether in solid or liquid form, must be collected and stored, or buried at sea or on land. In some cases it is possible to reduce the volume and concentrate the waste by burning, but care must be taken not to release the radioactive dust into the air.

Contaminated water of low activity may be allowed to soak away through the soil, which will absorb much of the activity. In an emergency, the disposal of contaminated water into the sewage system might be permissible.

In the case of burial of solid material (or soak-away of water) the site must be marked so that subsequent accidental exposure to the residual activity may be avoided.

8.8. Recommended Decontamination Agents - Composition and General Application

The agents listed in this section are based on an A.W.R.E. Report (Reference (1)), but have been amended to include some more recent formulations recommended by the author of that report.

A. Detergent

"Fully-built" synthetic detergents are far more effective than the simple "unbuilt" detergents, although the latter are better than nothing.

A suitable formulation for the fully-built type is as follows:-

Alkyl aryl sulphonate (Nervan EL.)	2.5 parts
Sodium Tripolyphosphate	8 parts
EDTA Acid	0.25 parts
Cellofas	0.25 parts
Soda Ash	1 part

This may be used at 0.3% w/w upwards. (5 oz./10 galls. upwards).

Uses - All general work, especially on smooth surfaces.

Hazards - None, c.f. normal domestic detergent.

B. Strong Alkali with Detergent

Any strong alkali may be used; caustic soda is very strong and cheap and is thus very suitable. Use 3 to 16 ozs. per gallon of solution as the severity of treatment demands. $1\frac{1}{2}$ ozs. per 10 gallons addition of a wetting agent or detergent (Lissapol N is suitable) will aid the penetration of this solution.

Uses - Paint stripping etc., quickest when hot. Use at full strength. Degreasing - more dilute solutions may be used, or caustic soda replaced by sodium metasilicate or trisodium phosphate. More efficient when hot. May be used in conjunction with a scouring powder such as pumice. May not be used on aluminium and magnesium alloys.

Containers - Steel buckets, cans and tanks are suitable.

Hazards - Corrosive; must be kept away from skin, tongs and/or rubber gloves should be used.

C. Complexing Detergent Solution

An example of this is SDG3, which comprises:-

EDTA Acid	1 part
Citric Acid	2 parts
Sodium Carbonate	0.6 parts
Water	1 part
Alkyl Sulphate Detergent (20%) solv.	1.5 parts
Sodium Sulphate (anhydrous)	2.5 parts

The normal working strength is 0.8% w/w. The pH valus should be 3-4. A considerable improvement will result from the addition of one part sodium fluoride, but the mexture will then be poisonous.

Far more effective if used hot or with steam.

Uses - The above preparation is more effective if used as a bath treatment or applied as a cream after thickening with 2% w/w sodium alginate (Manutex SA/KP) and left for a short time to act, rather than if used as a straight wash down as a detergent. The solution is suited to all surfaces, especially paint, plastics, non-ferrous metals, glass and textiles.

Containers - Enamel buckets and cans are very suitable, but where these are not available steel or galvanized buckets or tanks may be used, in which case it is preferable that they be given one or two good coats of paint, preferably bitumen paint, on the inside. Stainless steel is the ideal material, brass is a reasonable second best.

D. Laundry Detergent

The solution given under Type A above will prove adequate for the treatment of clothing in commercial laundry machines. Where soft water is available a soap-based detergent liquor is to be preferred, for example:-

	Nominal Washing Strength
EDTA Acid	0.02% w/w
Soda Ash	0.09%
Sodium Tripolyphosphate	0.2%
Cellofas B or D	0.01%
High Titre Soap	0.1%

In severe cases the EDTA and Soda Ash content may be raised to 0.05% and 0.12% respectively. The pH value should be 9.5.

The process may follow the standard pattern, but without any initial breakdown soak. In a two-wash process the first wash may be at 140 - 160°F, the second up to boiling if the goods will allow. The exact quantity of stock solution will vary according to conditions.

Severe contamination of clothing may be removed by an overnight soak in the Complexing Detergent Solution, after the above process.

E. Detergent

This is a special detergent for grease and possesses very good emulsifying powers. The only British detergent of this type is Lissapol N (I.C.I.), (Stergene), and may be used at strengths between 4 and 80 oz. per 10 gallons. In cases where a reactive contamination is present, a complexing agent (Sequestrol M, 8 oz. per 10 gallons) may be added with benefit.

Uses - Degreasing and cleaning of surfaces generally, but particularly where strong alkali, etc., is undesirable.

Hazard - None. Prolonged contact with skin should be avoided.

Note - This detergent is normally cloudy in hot solutions. It rinses off better in cold water.

F. Scouring Powder

Fine pumic powder or any proprietary scourer may be used here. A more satisfactory preparation is made if a detergent and complexing agent are also added. The following is a very satisfactory preparation and is non-drying:-

Scouring paste:	8% SDG3 (vide C)	30 parts dry weight
	300 mesh Pumice Powder	40 parts
	Glycerine	20 parts
	Sodium Alginate (Manutex SA/KP)	1 part

Uses - General cleaning of all non-porous surfaces, especially hard materials. Very useful decontaminant where non-abrasive methods fail.

Hazards - None. Many other abrasive powders, e.g. titanium oxide, felspar, etc., may be used in place of pumice.

G. Acids

A wide range of acids may be used where such are permissible. For ferrous materials standard rust removing acids are satisfactory, e.g. sulphuric acid, at 1-25% strength.

Other good mextures are:-

a - oxalic acid (1% upwards)

b - 6% nitric acid plus 1% sodium fluoride

c - 2% oxalic acid plus 1% sodium fluoride.

Uses - These may be used on almost any surface where fast or highly efficient decontamination is required. Metals will tend to dissolve, and glass will be etched to some extent by the fluoride solutions.

References

(1) A.W.R.E. Report No. O-49/55 - "A Guide to Radiological Decontamination after a Nuclear Explosion or Radiological Attack". (Official Use Only)

8.9. Recommended decontamination techniques for specific cases.

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Asphalt, Bitumen	Water from hoses, with brushing		Very effective for inert dust, less effective for reactive contamination; erosion.	Work from less active to more active areas, and downhill on sloping surfaces. Brushing may be used with advantage.	Activity will collect in gullies and drain traps. Suitable for large areas. Avoid undue spray.
	Scrubbing with detergent	A	All types of contamination.	As above.	Suitable for smaller areas.
	Strong alkali with detergent	B	Ditto Dissolves surface.	Work in small patches Sluice down with water after treatment.	Suitable for smaller areas.
	Complexing detergent solution.	C	Effective for reactive contamination. Dissolves contamination.	Work in small patches, apply solution, keep wetted with spray if necessary, leave for 30 minutes or longer and finally wash off. Use as hot a solution as possible.	Applicable to small special areas. Solution is relatively expensive.
Brick Concrete	Vacuum cleaning (preferably with brush)		Suitable for dry dust contamination on rough surfaces.	Usual technique, work downwards.	Special machines are preferred. Machine becomes contaminated. Means of safe disposal of effluent air are required (special filters). (Respirators may otherwise be required).
	Hosing down and brushing		Suitable for inert dust, and on relatively smooth surfaces.	As for Asphalt	Wetting is likely to fix reactive contamination in the surface layers.
	Flame cleaning		All types of contamination. Spalling of surface.	Hot oxyacetylene flame used.	Useful in some cases. May be used prior to grinding or blasting.
	Surface grinding or blasting		All types of fixed contamination. Abrasion and removal of surface.	Any of the usual techniques may be used. Work downwards.	It may be preferable to wet the surfaces first. Operator will require respirator.
Clothing	Vaccum cleaning		Useful for dry dust contamination.	Use small nozzle.	Sometimes useful prior to laundering. (See remarks under Brick and Concrete)
	Normal laundering (preferably soap, sodium pyrophosphate and carboxymethyl cellulose, otherwise usual detergents)		Best method for inert contamination.	Normal laundering methods. Soap and soft water far superior. Avoid excessively alkaline conditions. First wash at pH 10, following washes initially pH 8, rising to 10.	Means for effluent disposal required.
	Special procedures. Soap wash, followed by a soak in complexing detergent solution.	D	Best method of reactive contamination.	Usual laundering methods but with addition of a soaking stage. (Stir occasionally during soaking). Alternatively boil with complexing solution 15 minutes (see text)	Special chemicals required, but other methods will have little effect. Wool is more difficult to decontaminate than cotton and other fabrics.

Surface or Article	Decontaminating Agent	Ref. Sect. No.	Type of Contamination and Action	Procedure	Remarks
Waterproof Clothing (Rubberised and Oilskins)	Detergent	A	Inert dust and reactive contamination	Wash down and scrub any high spots, rinse down with water (Only cold or warm water is admissible)	Seams are liable to retain activity.
	Complexing detergent solution	C	Reactive contamination	As above. A long soak may be used if necessary. Preferable to use warm solution.	
	Fine pumice or other scouring powder	E	All types of contamination	Scrub with reagent and rinse well. Repeat if necessary.	Most effective treatment.
Canvas Rope, etc.	Vacuum cleaning		Dry dust contamination.	Use fairly small smooth nozzle.	Useful first step. See remarks under Brick and Concrete)
	Detergent	E	Inert dust and reactive contamination.	Scrub down, hot water if available, rinse off well.	Canvas and rope work are difficult to clean.
	Complexing detergent solution	C	Reactive contamination.	Soak with occasional agitation for as long as permissible, and as hot as permissible.	
Glass	Detergent	A	All types	A normal wash down or scrub if necessary. Work downwards.	Inspect any frame or mounting for holes prior to washing. If leaky frames are found, wash with damp cloth rather than with excess water.
	Complexing detergent	C	Reactive contamination.	As above. Use warm solution.	As above. This treatment should be necessary only in severe cases, or possibly in less severe cases where the glass is frosted.
Greasy Surfaces (In all cases where grease is present, most of the contamination will be removed with the grease)	Emulsifying Solvent Cleaners e.g. 1 part Lissapol NX 1 part Lubrol MOA, 9 parts Kerosene		All types of contamination adhering to grease and oil films.	Work cleaner into grease deposit to dissolve. Hose off cleaner and dirt with high pressure hose.	Economical and Effective. Preferred Method.
	Organic Solvents. (Trichlorethylene, white spirit, Petrol, Kerosene, Cresol, etc.		All types of contamination (reactive contamination will be relatively unreactive in these solvents and the danger of fixation of contamination will be less)	Usual techniques. Washing down, using swabs dipped in solvent. Bathing in solvent. Solvent spray, etc. In each case wiping of the surface is desirable. Vapour degreasing will not be as effective.	Usual precautions necessary in the use of these solvents must be observed. Means for disposal or recovery of these solvents will be required. In the case of clothing normal dry-cleaning will be of little use.
	Steam (with detergents if available)		Inert contamination mainly.	Work downwards from the windward side of work.	
	Hot detergent	E	Mainly inert contamination or reactive contamination if complexing agent is added.	Hot bath, spray, or hose depending on object and size.	Useful for light aluminium and magnesium alloys.
	Strong alkali with a little detergent	B	As above	Hot or boiling, bath or hose.	Not suitable for above metals. Avoid splashing and spray. Means of disposal required. Dilute if necessary.

Surface or Article	Decontaminating Agent	Ref. Sect. [illegible]	Type of Contamination and Action	Procedure	Remarks
Hard grease and grime	Fine pumice or other scouring powder	F	All types of contamination. Abrasive	Rub on in paste or powder form, scrub if necessary. Wash off well. Work in small patches, one at a time.	Very effective where other methods fail. Suitable for small objects not of a precision nature.
Hair	Detergent	A	All types of contamination. Less effective for reactive contamination	Shampoo hair in warm water in normal way, repeat if necessary, rinse well	Any usual soapless shampoo is satisfactory.
	Complexing detergent solution	C	For reactive contamination left after above treatment	As above. Rinse well	Hair is difficult to decontaminate from reactive contamination. Usually safest to trim off hot locks.
Human Skin	Soap (Mild toilet) (Wood, flour or fullers earth may be added)		All types of contamination, especially inert	Wash well in soap and warm water scrubbing with a soft brush. Repeat until clean	Preferred procedure in all cases.
	10% Potassium permanganate, 2% Sodium bisulphite		All resistant contamination	Rub or swab on the permanganate solution for a minute or two, wash off, and decolourise with bisulphite applied similarly	Usually used only when the above fails. In the case of any cuts, wounds, sores, etc., medical attention should be sought.
Metals (see also Surfaces)	Hosing and brushing with water		Mainly inert contamination	See remarks for "Asphalt"	Useful for large areas
	Detergent	A	As above	See remarks for "Asphalt"	
	Organic Solvents and Emulsifying Solvent Cleaners		All types of contamination	See remarks for "Greasy Surfaces"	
	Complexing detergent solution	C	Reactive contamination	Wash down in normal manner	Suited to light metals which would be attacked by more severe treatments. (e.g. aluminium alloys)
	Fine pumice or other scouring powder	F	All types of contamination	See Remarks under "Hard Grease and Grime".	Suitable for all metals but not on precision parts
	Metal polish		All types of contamination	Usual method of application, change rags frequently	Suitable for small and delicate parts
Heavy metals iron and steel etc.	Industrial de-rusting agents, especially inhibited phosphoric and other acids	G	All types of contamination	Soak in bath with occasional brushing, hose down, or wash down with the solution. Rinse well afterwards, dry, and grease to prevent rusting.	Fast and complete decontamination. Acid should be handled with care and splashing avoided
	Sand blasting (preferably wet)		All types of contamination	For dry sand blasting a special box is preferable. Wet sand blasting less hazardous	Complete surface removal with accompanying damage. Contamination may be spread over large area. Suitable only for large rough objects.

Surface or Article	Decontaminating Agent	Ref. Sect. 9.9	Types of Contamination and Action	Procedure	Remarks
Paint	Hose and brush down with water		See remarks under "Asphalt"		First step in dealing with large areas, particularly in cases of inert dust contamination
	Detergent	A or E	As above		Run off water should be controlled, and not allowed to flow towards clean areas
	Complexing detergent solution	C	Reactive contamination	See remarks under "Asphalt". Use hot solution (Preferably PH5)	In case of buildings care should be taken to see that contaminated water does not flow into or be driven into an uncontaminated interior.
	Fine pumice powder or other scouring powder	F	All types of contamination	See remarks under "Hard Grease and Grime"	
	Trisodium phosphate		All types of contamination	Rub surface for a few minutes with rag moistened with hot 10% solution, wipe dry, use clean rag for subsequent application	Surface removed. As above
Stripping Agents	Steam (with detergent (if available)		See remarks under "Asphalt"		
	Strong alkali preferably with a little detergent	B	All types of resistant contamination	Soak surface or paint on, leaving for 1 to 2 hours, hot or cold, wash off, and scrape off any remaining paint	Complete stripping of paint. Not suitable for aluminium or magnesium alloys. Splashes should be avoided.
	Organic solvents, e.g. trichlorethylene, and industrial paint stripping compounds		All types of contamination	Immerse, wash and scrape or use usual methods of application in the case of industrial strippers	Should be used in a well ventilated space and usual precautions for solvents taken.
	Burning off		All types of contamination	Usual technique, burn and scrape	Useful for exterior paintwork window panes, etc., only. Hazardous.
	Sand blasting		See under "Heavy Metals etc."		Suited to hard finishes, e.g. vitreous enamels.
Plastics	Detergent	A	) See remark under "Glass"		
	Complexing detergent solution	C	)		
	Fine pumice powder or other scourer	F	See remarks under "Hard Grease and Grime"		
	Metal Polish		All types of contamination	Use in normal manner, replace rag at frequent intervals	Useful on hard smooth plastics, e.g. perspex and bakelite

Surface or Article	Decontaminating Agent	Ref. Sect. 8.8	Type of Contamination and Action	Procedure	Remarks
Leather	Water		Inert dust contamination.	Polished leather may be cleaned, by wiping with a damp cloth	
	Brushing		As above.	A good brushing in the welts will help to remove dust from boots.	
	Organic Solvent		All types of contamination.	Wipe polished leather with a cloth dipped in a solvent will remove activity with the polish and oils.	Leather so treated should be repolished immediately.
	Wire Brush or Sanding		All types of contamination when dry.	A good stiff brushing with a wire brush will be effective in removing the surface layer.	Avoid dust. Suitable for soles and heels. Failing this, leather should be discarded.
Rubber	Detergent	A	Inert contamination mainly.	Good wash down, and scrub, preferably hot.	First step in decontamination of rubber.
	Detergent	E	Inert contamination held by grease.	As above.	This is preferable to the use of organic solvents.
	Organic Solvents, especially acetone. (not recommended for general use)		All types of contamination.	Swab over <u>quickly</u>, do not allow the solvent to remain in contact for long.	<u>Not recommended for general use</u>, suitable for greasy patches only.
	Complexing detergent solution.	C	Reactive contamination.	Soak goods in hot solution, or wash down. Length soaking is more efficient. Rinse well. (Rubber may be boiled in this solution with benefit)	Applicable to all types of rubber.
	Acids, industrial de-rusting agents, e.g. inhibited phosphoric acid.	G	All types of contamination, especially reactive.	Soak goods in solution for as long as permissible, or in case of large objects wash down. Brush. Rinse well.	Most rubbers are resistant to these compounds. Care will be required in their use, splashes should be avoided.
	Fine pumice or other scouring powder	[illegible]	All types of contamination.	Rub on in usual manner, wash off well.	Surface abrasion. More suited to hard rubbers.
Soil	Land scrapers and bulldozers		All types of contamination.	Soil should be damp but not wet.	Only method available. Means for burial or other disposal of large quantities are required.
Tile and Slate	Vacuum cleaning		Suitable for dry dust contamination.	See remarks under "Brick and Concrete"	Useful for porous and rough surfaces.
	Hose down and brush		Mainly inert contamination.	Work downwards, directing hose down slope. Brushing down will be an advantage.	Care should be taken to avoid the entry of water into uncontaminated building interiors.
	Trisodium phosphate or other strong alkali	B	All types of contamination.	Scrub hot 10% solution onto surface flush down with water.	Surface removal. Good for floor tiling.
	Surface grinding or blasting.		See remarks under "Brick and Concrete"		

Surface or Article	Decontaminating Agent	Ref. Sect. 6.8	Type of Contamination and Action	Procedure	Remarks
Wood (Unpainted	Vacuum cleaning		Mainly inert contamination	(See remarks under "Brick and Concrete"	Useful for flooring, especially rough surfaces.
	Scrubbing with Detergent	A	Mainly inert contamination.	Work downwards, avoid entry of water into uncontaminated areas and spaces.	Suitable for upright woodwork, weather-boarding, etc.
	Planing, scraping, sanding.		Suitable for all types of contamination. (Surface removal)	Conventional techniques. Preferable to wash down as above, and allow to dry prior to present treatment.	Suitable for floors, table-tops, etc. but laborious. (Dust hazard)

All the Tables in this Section are reproduced from A.W.R.E. Report No. O-49/55 "A Guide to Radiological Decontamination after a Nuclear Explosion or Radiological Attack" (Official Use Only)

CHAPTER 9 - RADIAC INSTRUMENTATION

The term "RADIAC" is a contraction of the phrase "Radiation Detection Identification And Computation" and is an international and inter-Service term applied to instruments designed for use by personnel involved in atomic warfare, for various monitoring processes which are discussed below.

9.1. Types of Radiation.

The types of radiation emanating from a nuclear explosion have been discussed in Chapters 1-3 of this Part of the Manual, and definitions are given in Part II (Glossary).

There are four main types of nuclear radiations resulting from an explosion, namely:-

(a) Gamma-rays
(b) Beta particles
(c) Alpha particles
(d) Neutrons.

Of these radiations, alpha particles constitute a hazard which is likely to be met only in special circumstances, e.g. the disposal of unfissioned material, and hence the measurement of alpha particles is not included as one of the standard requirements for a Radiac instrument.

Beta radiation constitutes a definite part of the residual radiation from an atomic explosion, i.e. from the fallout. Considerations for and against including beta measuring facilities in Radiac instruments are discussed in Section 9.3.

Gamma radiation resulting from an atomic explosion may be considered in two categories. Firstly, that from the actual explosion itself ('prompt', 'initial', or 'immediate' gamma radiation), and secondly, that from the fission products which fall out ('residual' radiation). Radiac instruments are designed to measure gamma radiation.

Surplus neutrons from the fission process can escape from the actual explosion, and in the case of a comparatively low burst, can reach the ground.

In most practical situations the other bomb effects are more likely to be lethal than the neutrons, and so no provision is at present made for neutron measurement in Radiac instrumentation.

In the Armed Services and Civil Defence Service*, instruments are therefore required for the following purposes:-

(a) Measurement of doses of gamma radiation received by personnel.

(b) Measurement of dose-rates from the radioactive contamination of ground, etc.

(c) Measurement of dose-rates from the radioactive contamination on the clothing and bodies of personnel, and on vehicles, etc.

(d) Measurement of the degree of contamination on food and in drinking water.

(e) Measurement of radioactivity for specialised purposes.

(f) Training.

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* Subsequently in this chapter, "Service" will imply the Armed Services and Civil Defence.

9.2. Measurement of Personal Doses (Flash Dosimeters)

There are two types of radiation dose which are important to the individual - initial radiation received from the actual explosion, and residual radiation, received from the radioactive cloud or from fallout deposited on the ground.

It has been stated (reference Chapter 2) that a single dose of 450 roentgens will cause the incapacitation within 24 hours of all who receive it, and ultimately the death of about 50% of the recipients. An instrument is therefore required that will measure doses of gamma radiation of up to (say) 500r when emitted at a very high dose-rate. Such instruments have been termed "Flash Dosimeters" and may be of several types, described in Table 1. While all the following principles are theoretically sound, work in the U.S., Canada and this country has shown that several methods are unsuitable for Service use. Comments on this are given in the last column of the table.

Of the types listed in Table 1, only 'd' and 'e' - the Phosphate Glass and Quartz Fibre Dosimeters - are in British Service use.

The dose-rate at which doses from residual radiation are received is very much lower, and any instrument designed to work under high dose-rates will operate in these lower conditions. However, the dose to be measured is also appreciably lower. The flash dosimeter is intended basically for use by Service or emergency medical organisations to enable assessment of the correct treatment, and by the Commander in the field to assess the fighting potential of his troops. A dosimeter intended for measuring residual radiation (or radiation from a radioactive source or reactor) is intended to give a measure of the radiation received by an individual, and so ensure that he does not receive more than the tolerable dose for the particular circumstances. Thus a radiation worker in an establishment using a reactor or in a store holding radioactive sources would be restricted to 0.1r per week, while troops in the field or Civil Defence personnel in an emergency might have to be subjected to a single dose of 25r or even higher.

For reasons of sensitivity only photographic, phosphate glass and quartz fibre types of flash dosimeter are suitable for measuring doses of less than 50r. The photographic dosimeter is unsuitable in the field, as already stated, for technical reasons.

The Phosphate Glass dosimeter is suitable for Service use where incremental doses of (say) 10r or more, are of importance.

The Quartz Fibre dosimeter (designed so that the instrument is of the correct range) will cover any maximum dose from 0.5r to 500r, or even higher. Selection of a suitable range is therefore possible. Thus workers in Ordnance Depots holding radioactive sources use the 0 - 0.5r instrument; troops in the field would carry the 0 - 50r or 0 - 150r instruments as well as the 0 - 500r.

The term "Flash Dosimeter" has been used here to describe a dosimeter suitable for use in measuring initial radiation, i.e. that received at a very high dose-rate. The official Service terms "tactical", "residual" and "technical" are used to denote dosimeters of varying ranges and uses. Broadly speaking the tactical dosimeter is intended for measuring the large doses of radiation received at high dose-rates from the actual

nuclear explosion and enables a quick assessment of the fighting potential of the troops to be made. The residual dosimeter is used to measure the gamma dose received by its wearer when operating in a radioactively contaminated area. The technical dosimeter is used to measure the dose received from low activity radioactive sources and, as such is worn by personnel handling training sources etc.

TABLE 1 - Types of Flash Dosimeter

Type	Principle	Comments
a. Photo-graphic	Ordinary film, (in this case "dental film" used for X-ray photographs of teeth) is blackened on exposure to gamma radiation. The density of the blackening can be measured and converted to a measurement of dose.	This method is used in Atomic Energy Establishments etc. where processing may be done under controlled conditions. "Service" types incorporating a developer are not particularly suitable and have tended to be rejected in favour of better principles. Low cost.
b. Chemical	Gamma radiation will cause the formation of HCl from a mixture of a chlorinated paraffin (e.g. carbon tetrachloride) and water. The amount of HCl formed, expressed as a pH value is related to the dose and may be measured by the colour change of suitable indicators.	Used in the U.S. - Individual Dosimeter E1R3, consisting of five tubes designed to change colour at 50, 125, 175, 300 and 450r respectively. Dosimeter reacts to sunlight and is generally not very reliable. Fairly low cost.
c. Crystal	Crystals of alkali halide (e.g. potassium chloride) become coloured on exposure to gamma radiation. Colour may be matched against samples mounted contiguous to the crystal or on some colorimeter.	Colour matching by eye is difficult as it is only the depth of colour that is affected by additional doses. Provision of a colorimeter would increase the cost. Crystal bleaches in strong light which is a disadvantage although it means that the crystal can be intentionally bleached and re-used.
d. Phosphate Glass	A phosphate glass activated with a small quantity of silver, will fluoresce under U.V. light after irradiation by gamma-rays. The fluorescence is measured and compared against a standard, the ratio being converted to give a meter-reading in roentgens. The reader can be operated from the mains or other equivalent supplies powered by wet batteries. Operation from dry batteries would require a special design of reader with low current consumption.	Dosimeters cost about 5s.0d. but reader costs about £150. A satisfactory type of dosimeter where incremental doses of less than about 10r do not have to be measured, i.e. on operations.

Type	Principle	Comments
e. Quartz Fibre Dosimeters	Consists of an ionisation chamber to detect the radiation, with a gilded quartz fibre electrometer which is read through an optical system built into the dosimeter. The instrument which is normally the size of a large fountain pen is charged up to read "zero". Gamma radiation causes the dissipation of a proportion of the charge, the amount being read on the electrometer as a reading in roentgens. Chargers may consist of a source of H.T. from batteries (i.e. a 150 volt battery or a L.T. battery and vibrator or transistor unit) or an electromagnetic unit incorporating a hand generator. The last type is used in British chargers. Some means of transferring the charge from the charger to the dosimeter and of adjusting the charged dosimeter to read zero must be incorporated.	Cost about £5 each. Very robust. Owing to difficulties in collecting all the ions formed in the ionisation chamber when the instrument is exposed to higher dose rates, these dosimeters tend to under-read when measuring full-scale doses of 'prompt' radiation, if their scales have been calibrated on doses applied more slowly. The correction factor on an existing design of 500r dosimeter (the QF No.5) is about x1.4, but it is feasible to design 500r dosimeters with substantially complete collection under flash radiation conditions.

9.3. Measurement of Contamination of Areas (Survey Meters)

Instruments designed for reconnoitring and surveying contaminated areas are now known as "Survey Meters". This is an inter-Service and standardised NATO term which replaced the old U.K. term "Portable Dose-Rate Meter".

In view of the fact that a dose of 25 roentgens can be accepted as a military tolerance in operational conditions, and also the fact that the activity of the fallout of an atomic weapon decays according to the $T^{-1.2}$ law, the ranges required on the Service survey meter are probably 0.05r/hr to 300r/hr, but the majority of readings will not exceed 3r/hr.

Measurement of dose-rates such as these can be easily carried out with a simple ionisation chamber/electrometer valve circuit, in which the ionisation current is used to develop a voltage across a high value resistor in the grid circuit of a specially designed triode called an electrometer valve. Any change of this voltage is measured by a microammeter in the anode circuit. The usual principle is to use three different grid resistors varying by 10:1 ratios and hence have three ranges on the instrument, e.g. 0 to 3, 0 to 30, and 0 to 300 r/hr.

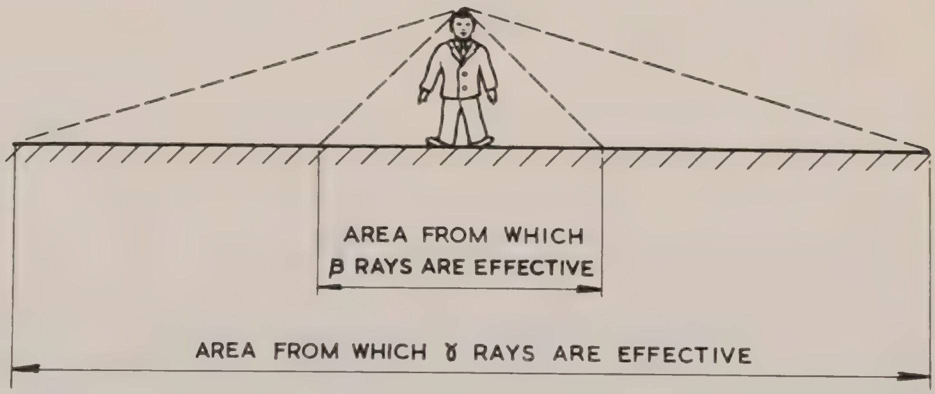
As an alternative to this, the pseudo-logarithmic characteristic which results from a free grid circuit may be used. In this circuit the ionisation chamber current is balanced against the grid current, the change in anode current being measured by a meter. In this type of meter the three decades 0.5 r/hr to 500 r/hr may be read without switching.

In their basic design, survey meters are sensitive to gamma radiation only, as the ionisation chamber is usually enclosed in a metal or plastic case. If however, the ionisation chamber has one side closed with a thin window (of surface density not exceeding about 40 mg/cm^2), then any beta particles incident on this window with energy exceeding a certain threshold will penetrate the window and cause ionisation in the chamber. It is therefore possible for the instrument to indicate the presence of beta radiation. If some form of shutter is fitted to the beta window, it is possible in a given field to obtain a measurement of the gamma dose-rate when the shutter is closed and an indication of the beta + gamma dose-rate when the shutter is open. (The beta hazard is of some importance with fission product activity.) The ratio of beta dose-rate to gamma dose-rate will depend on the terrain over which the measurement is taking place since the beta radiation is of less effective range than the gamma. Hence, in the two circumstances shown in Figure 1, in (a), the man is receiving gamma radiation from a distance as well as from his immediate vicinity, while the beta radiation is received effectively from his immediate neighbourhood only. In (b), the gamma dose-rate is appreciably reduced by the surrounding buildings while the beta dose-rate is the same. Thus an instrument which measures gamma radiation only will give a lower reading in case (b), while in fact the beta dose-rate is the same. If therefore an estimate of the latter is based on a particular beta/gamma ratio, an erroneous conclusion will be formed in one case.

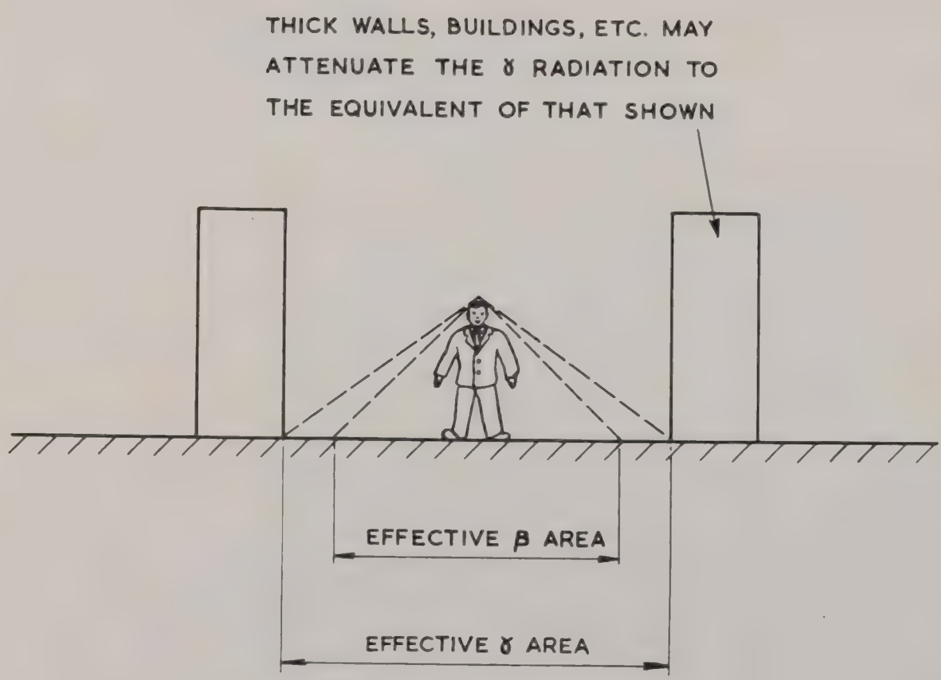
In addition, the beta/gamma ratio depends also on the beta energy spectra of the fission products, which vary with time. Typical figures for beta/gamma ratios for plane surfaces are 15:1 a few hours after burst, dropping to 4:1 after three weeks, and then rising slightly after three months.

The beta dose associated with a gamma dose of 25r is estimated to be about 300 rep, and hence the beta hazard will not normally be in excess of that estimated from the gamma hazard. However, these ratios apply to measurements at about three feet from the ground. In cases where the fission products are in contact with or close to the skin, e.g. when a man is lying down, the figures are much higher - figures of over 100:1 have been mentioned. In these cases, the beta hazard may exceed the gamma hazard, but may still be estimated from the gamma measurement if certain basic assumptions are made.

A certain degree of interference from radar is experienced by ionisation chamber instruments that are not screened, i.e. have non-metallic cases. The interference occurs mainly in the centimetric and millimetric bands (10,000 Mc/sec - 3,000 Mc/sec) and may manifest itself as either a negative or a positive reading. The trouble occurs only when the instrument is in the direct beam of the radar set and then only when within (say) 200 yards of it. It can be prevented by encasing the instrument in a metallised bag or in a thin metal carrying case.



(a) RELATIVE EFFECTIVE AREAS IN OPEN



(b) SITUATION IN BUILT-UP AREAS, IN SHELL HOLES ETC., WHERE THE β RADIATION IS THE SAME AS IN (a) BUT THE ɣ RADIATION IS MUCH REDUCED

EFFECT OF TERRAIN ON RELATIVE
BETA AND GAMMA RADIATION HAZARDS

9.4 Measurement of Contamination on Personnel, Food and Water (Contamination Meters)

The hazard from contamination of the skin and clothing is mainly a beta radiation hazard, but may be estimated in terms of the response of a gamma-sensitive instrument held at a standard distance from the body. If this distance is chosen as 50 cm. then an instrument measuring up to 50 mr/hr. is required in order to discriminate between excessive contamination and that which is permissible by emergency standards.

Instruments meeting these requirements are called Contamination Meters. In view of the sensitivity required, an instrument incorporating a Geiger-Mueller tube is desirable. The Geiger-Mueller tube is a form of ionisation chamber working at a polarising voltage sufficiently high that each individual ionising event in the tube will initiate a discharge of standard size in the tube. The meter consists of the necessary amplifying circuit together with a pulse counter or a counting-rate meter. In the Service instrument, a counting rate meter is used and there is a facility for using earphones as well. The aural indication is an added help to the monitor as the increase in the well-known Geiger "clicks" in the earphones will call his attention to the high rate being shown on the dial.

Geiger-Mueller tubes, like the ionisation chambers of Survey Meters, will admit beta particles only if the walls of the tube are thin enough. As the G.M. tube is usually of glass, it then becomes very fragile and so a beta-sensitive tube is normally fitted into a probe with a metal "can' around it. A sliding window is opened to make the instrument beta-sensitive. In the case of British Service 'field' instruments the tube is sensitive to gamma radiation only, the beta hazard being estimated from the gamma measurements.

To measure the contamination on the person, two methods may be used:-

(a) the probe is placed at about waist height and the subject under test rotates once at a point about two feet in front of the probe, or

(b) the probe is used as a 'frisker', i.e. is run over various parts of the body in turn.

Both methods are possible with the current Service instrument.

The use of a Geiger counter instrument for this purpose has xcertain disadvantages however. The usual method of measuring contamination on the person, described as method (a) above, involves a fairly sensitive instrument, as it has to measure the activity from a comparatively small amount of contamination two feet away. This results in the instrument being very sensitive to a gamma background and in practice a background exceeding about 2 mr/hr. will effectively mask any readings. It is possible to erect shielding around the instrument, but as this shield has to be large enought to enable the subject under test to move around inside, it will be appreciated that a fairly large sandbag edifice will be required.

It is therefore preferable to use a less sensitive instrument which has to be held closer to the contamination. This has the effect of enhancing the reading from the contamination and minimising the

/background

reading. Trials at Operation Buffalo indicated that an ionisation chamber instrument of design similar to the Survey Meter No. 2, with a beta-sensitive ionisation chamber, was capable of being used as a 'frisker' in quite high backgrounds. As an example, a degree of contamination which would give slightly under a full-scale reading on the Contamination Meter No. 1 used as in method (a) above, gave a reading of 1.5 r/hr. on the Survey Meter No. 2 used as a 'frisker' with its beta window open. The background was 100 mr/hr - ten times full-scale on an unshielded Contamination Meter No. 1 but only 1/30 full scale on the bottom scale (0 to 3 r/hr) of the Survey Meter No. 2.

The advantage of using a beta-sensitive instrument is two-fold; firstly, the range of the beta particles is sufficiently small that the instrument can delineate the boundaries of the contamination more accurately, and secondly, the ionising capabilities of beta particles are greater than for a similar number of gamma photons, hence an enhanced reading is obtained. The scales of instruments calibrated for gamma radiation only indicate the degree of beta radiation, and do not measure in any particular units.

As a result of this, future policy, at least for the Army, will be in terms of a combined Survey/Personal Contamination Meter as it will be technically possible to combine the two instruments. This is also very convenient tactically.

A sensitive instrument is required for monitoring food and water, as the degrees of contamination liable to prove hazardous on ingestion are relatively low.

The Contamination Meter No. 1 is suitable for this purpose, and is used as a 'frisker' for measuring the contamination on food.

To measure the contamination in water, the probe may be held at a fixed distance from the water, or alternatively, a special beta-sensitive G-M tube into which a sample of the water may be poured, can be used.

Special devices have been developed to measure long-lived alpha activity in personnel, food, air and water.

Item	Name	Joint Services Catalogue No. 6665-99-911-	A.E.R.E. No.of Prototype	Capabilities	Services using instrument	Production Situation (May '57)	Remarks
11	Meter Survey Radiac No.2	-0008	-	Reads 0 to 3, 0 to 30 and 0 to 300 r/hr. Fitted with beta window	Army, R.A.F. C.D.	P	
12	Meter portable dose rate trainer No. 1	-0010	1191B	Reads 0 to 3 x 10^{-4} r/hr	Army, R.A.F. C.D.	S	Superficially resembles Item 10
13	Meter Survey Radiac No. 3	-0123	1324A	Reads 0 to 30, 0 to 300 and 0 to 3000 mr/hr	Army, R.A.F.	P	For use in stores holding R/A sources
14	Meter Survey Radiac No. 4	-0124	1349A	Reads 0 to 15, 0 to 150 and 0 to 1500 mr/hr	-	-	Beta/gamma sensitive. Mainly for trials use.
15	Meter Contamination No. 1	-0012	1092D	Reads 0 to 10 mr/hr with gamma probe and 0 to 10 mr/hr. with special beta sensitive liquid (re-entrant) probe.		S	All contained in one haver-sack. Powered by H.T. batteries OR L.T. batteries + vibrator OR Mains
16	Monitor Radioactivity No.1	-0258	1257B	Sensitive to α, β and γ radiation. Reads in counts/sec.	Army, R.A.F.	S	Mains operated. Service version of A.E.R.E. 1021. Title is that used in Army; other Services may vary.
17	Source Radioactive A No.1	-0015	1210A	0.5 mC of Radium. Gives 0.5 mr/hr at 1 yd.	All	S	Used for checking instruments
18	Source Radioactive B No.1	-0016	1210A	100μC of Cobalt. Gives 0.16 mr/hr at 1 yd.	All	S	Used for wearing as "contamination"
19	Source Radioactive C No.1	-0017	1210A	1 mC of Cobalt. Gives 1.6 mr/hr at 1 yd.	All	S	Used for demonstration and training

Item	Name	Joint Services Catalogue No. 6665-99-911-	A.E.R.E. No.of Prototype	Capabilities	Services using instrument	Production Situation (May '57)	Remarks
20	Source Radioactive D No.1	-0018	1210A	5 mC of Cobalt. Gives 8 mr/hr at 1 yd.		S	Used for demonstration and training.
21	Source Radioactive E No.1	-0019	1210A	25 mC of Cobalt. Gives 40 mr/hr at 1 yd.	All	S	Used for demonstration and training.
22	Source Radioactive F No.1	-0025	-	25 mC of Cobalt	All	S	Used for calibrating instruments.
23	Source Radioactive G No.1	-0041	-	5 mC of Cobalt	All	S	" " "
24	Slide rule Radiac No. 1	-0027	-	Will calculate future or past dose according to $T^{-1.2}$ law.	R.N.	S	
25	Radiac Calculator No. 1	-0060	-	" " " " "	Army, R.A.F. C.D.	S	
26	Water Contamination Calculator No.1.	-0057	-	Will calculate hazard due to drinking contaminated water, knowing time after burst	Army, R.A.F. C.D.	S	Obsolescent for Army and R.A.F.
27	Meter Survey Avo, No. 1	NYA	1219	Reads up to 500 r/hr. on logarithmic scale		U/D	Alternative 100 r/hr. F.S.D. being developed for C.D.
28	Radiac Fallout Simulator	NYA		Will give magnetic field resembling "fallout" field	-	U/D	Two models giving "fields" up to 1000 yds. and 5 mls. respectively. Requires special "Survey Meter"

Item	Name	Joint Services Catalogue No. 6665-99-911-	A.E.R.E. No. of Prototype	Capabilities	Services using instrument	Production Situation (May '57)	Remarks
29	Test set, current sensitivity No. 2	-0112		Testing Item 11	Army, R.A.F. C.D.	S	

Abbreviations: NYA - Not yet allocated
U/D - Under development, P - In production, some available in Service, S - Produced and in service.

Note: The full J.S.C. No. for these instruments is in the form of a 13-figure reference, e.g. the J.S.C. No. of the Meter.

Survey Radiac No. 2 is 6665-99-911-0008

D1/57
September 1959.

Part VIII
Chapter 2
Preliminary

Chapter 2. Photographic Materials and Equipment.

D1/57
February, 1960.

Part VIII
Chapter 3
Preliminary

Chapter 3. Effects of Nuclear Weapons on Explosives

3.1 Introduction

3.1.1 Types of Explosives

Explosives may be classed into three main groups, namely:- initiating explosives, high explosives, and propellants. Initiating explosives are very sensitive and are readily detonated by small amounts of thermal, mechanical or electrical energy. As their name implies their chief use is to initiate detonation in the main explosive charge. Initiating explosives are too sensitive to mechanical shock and friction to be employed in more than minimum quantities and their explosive power is relatively low.

High explosives are filled into warheads, bombs, shell, etc. and are also used uncased for demolition purposes. They are much less sensitive than initiating explosives. The type of high explosive is carefully chosen to give the most efficient performance in the particular role required.

Propellants are not detonated but are burnt very rapidly under pressure so as to produce gases at high temperature which propel the shell or warhead along the desired trajectory.

3.1.2 Initiating Explosives

The more common initiating explosives are salts of heavy metals, for example, lead azide, lead styphnate, lead dinitroresorcinate (LDNR), and mercury fulminate, and are frequently mixed with other substances to obtain specific effects. Detonators for use in the initiation of explosive systems may have one or more initiating compositions pressed as increments, depending upon the particular use envisaged; their initiating power may be increased by filling the lower portion with tetryl. Initiating substances are also employed in "caps" for igniferous trains in propellant systems. For instance, in a gun cartridge, a cap is used to ignite the gunpowder in a primer which in turn ignites the main propellant charge. Mercury fulminate, which has relatively poor thermal stability, has been replaced by lead azide for use in detonators; and in cap compositions is being replaced by LDNR.

3.1.3 High Explosives

The most common high explosive substances used in the British Service are tetryl (trinitrophenyl-methyl-nitramine) slso known as CE, TNT (trinitrotoluene), RDX (cyclo-trimethylene-trinitramine), PETN (pentaerithritol-tetranitrate), and ammonium nitrate. Tetryl is mainly used as an intermediary between the initiator and the main explosive charge. Apart from TNT, which is frequently employed alone, the other materials are normally used in mixtures of which the following are the most common:-

Composition (Major Ingredients)	Designation
RDX/TNT	60/40 mixture known in U.S.A. as "Composition B"
RDX/TNT/Al with wax	Torpex
Ammonium Nitrate/TNT	Amatol
Ammonium Nitrate/TNT/Al	Minol
RDX/Wax	-
RDX/Wax/Al	-
TNT/Al	Tritonal
PETN/TNT	Pentolite
RDX/Oil or RDX/Grease	Plastic Explosive

The wax is added to high explosives to reduce sensitivity. Both TNT and the wax used in H.E. fillings melt at comparatively low temperatures, enabling the explosive to be cast from steam-heated vessels. This feature, while facilitating filling by casting, may lead to exudation through screw-threads if stores are heated to temperatures above 70°C. Aluminium is added to enhance blast and incendiary effects; explosives containing aluminium evolve gas on storage as a result of interaction between the aluminium and residual moisture and arrangements have to be made for the periodic venting of large thin walled stores, such as Naval mines and depth charges, to prevent distortion by internal pressure.

3.1.4 Propellants

Propellants may be broadly classified on the basis of their physical form into solid, plastic and liquid.

The traditional solid propellants, as used in guns, and in many rocket and G.W. applications, are usually based on nitrocellulose and nitro-glycerine. In this form they are termed "double base". Without the addition of nitroglycerine they are termed "single base". In addition the important class of "flashless" propellants for guns have a third major ingredient: picrite (nitroguanidine). Stabilisers must always be included to prevent a dangerous accumulation of the decomposition products of nitric esters. Other substances may be added in small proportions to achieve special properties, for example, inorganic salts to control burning rates or to reduce flash.

In recent years other types of solid propellant have been developed, principally for large rocket motors. In some of these, polymers other than nitrocellulose have been employed and large proportions of inorganic salts have been included as the main oxidant. Such propellants are sometimes referred to as "composite" propellants. Plastic propellants are a special form of composite propellant in which a large proportion of inorganic oxidant, for example, ammonium picrate and ammonium perchlorate, is suspended in an inert "binder" to give a putty-like material for direct filling into rocket motors.

Liquid propellants are usually single component, designated mono propellants, (for example iso-propyl nitrate) or have two components, for example, hydrogen peroxide/petrol, liquid oxygen/alcohol, nitric acid/aniline. In the case of two component propellants the components are stored separately until the moment of mixing in the rocket chamber and the explosive hazards in storage are thus reduced.

3.2 Blast Effects

The main effects of blast from nuclear weapons on explosives may be considered to be due to the direct effects of the blast wave itself, particularly the over-pressure, to the effects arising from displacement by the associated drag forces and to the effects of secondary missiles.

Before discussing these in some detail, it is perhaps advisable to state that in most applications of military interest explosives are not used bare, but are contained in a metallic or similar casing. There are some exceptions to this, notably the bare slabs of plastic explosive used for demolition purposes.

During research and development, explosive constituents are tested for their resistance to shock, etc. When an explosive is part of a store it has to withstand certain rough usage trials to ensure that it is not initiated, or rendered unsafe for normal use. Some of the more usual tests are discussed briefly below, mainly in order to indicate the magnitude of the blast or overpressure required to initiate the explosive.

For instance, during research into new initiating explosives, the suitability of a proposed composition is tested by its behaviour in the ball and disc impact test and in a friction test. In general it can be said that these tests are more severe than would be the case in practice, even when the store is subjected to the blast from a nuclear explosion. When it is used in a detonator which is fitted into a fuze or similar component, the initiating explosive is further tested for resistance to rough usage by dropping it 30 feet in a 65 lb. block on to a steel anvil.

The sensitiveness or susceptibility of high explosives to initiation by shock is tested during their development in two main ways, (1) by detonating a control sample of explosive at various distances from the sample under test (called the gap test), (2) by firing small steel pellets or fragments into the test sample at various velocities. In the former test the gap (which may be either air or a metal) between the samples is varied, in order to determine the distance at which 50% detonation of the sample is obtained. It has been found that the shock wave peak pressure required for detonation is of the order of some thousands of p.s.i. In the latter test the object is to determine the velocity at which 50% of ignitions of the sample is obtained. This test has shown that high velocity fragments (some thousands of f/s) are necessary.

The results of these tests have been roughly confirmed by trials in which stocks of ammunition have been exposed to the effects of blast and fragments from the detonation of large amounts of high explosives. These have indicated that there is little chance of initiating the explosive by fragments unless they are travelling at high velocities (thousands of f/s) and that blast overpressures have to be high to affect either boxed or unboxed ammunition. Following these trials it has been laid down for stocks of ammunition that the safe storage distance is $2W^{\frac{1}{3}}$ feet (where W is weight of H.E. in stack in lb.). This distance corresponds roughly to an overpressure of 500 p.s.i.

The initiation of propellants to ignition by shock or fragments also requires very high overpressures or very high fragment velocities. Both explosives and propellants can be initiated or ignited by being nipped between two surfaces. The basic principles involved in the ignition process of propellants may bear some similarity to that involved in the initiation of H.E., in that the latter can sometimes occur by a process of burning to detonation. There is also the possibility that the propellant charge

in a rocket or cartridge is damaged sufficiently by an impact to cause malfunction when used later, but in practice the external metal components would also be damaged, so that the ammunition would be discarded.

Before the blast wave reaches any particular target, that target has already been irradiated by the thermal and initial nuclear radiation. The effects of this irradiation are discussed in subsequent sections. In this section it is only necessary to surmise whether such irradiated material, which has not already been initiated, will be more liable to initiate by the subsequent shock from blast wave. No laboratory trials to test the overall effect have been carried out, but many explosives have been exposed to the effects of nuclear explosions (see references 1 and 2 at the end of this section).

The results of these trials have confirmed, with one possible exception, that peak blast overpressures of 100 p.s.i, and less do not directly cause the initiation of the main explosive components of ammunition. The exception consists of bare detonators which were initiated, but it is probable that many of these were set off by thermal radiation. Additionally, some slabs of plastic explosives have been exposed bare, and although most have been broken up and dispersed by the blast, there has been no evidence suggesting that the slabs have been initiated at peak blast overpressures below 40 p.s.i.

It can be concluded, therefore, that explosives and explosive stores will not be initiated by the blast effects, except at such small distances that the other components of the ammunition are themselves very seriously damaged.

From the results of Operations Totem and Buffalo it is apparent that ammunition exposed on the ground to a nuclear explosion is liable to be displaced considerably at distances where the peak blast overpressures are of the order of 15 to 20 p.s.i. With the possible exception, as before, of bare detonators, there have been no indications that the explosive components have been initiated by shocks sustained in this displacement, except by mechanical damage to the initiating mechanism.

As might be anticipated the effects from missiles have also been found to be insufficient to initiate the explosive components of ammunition, except through the normal explosive train (e.g., at least one percussion cap was initiated by a blow from a flying object).

References

1. AWRE Report T84/54. The Effects of an Atomic Explosion upon Ammunition. (Confidential).

2. AWRE Report (to be published). Operation Buffalo. Explosives Group Final Report, Part 7.

Other references on this subject will be found in the Bibliography, Part IX, Chapter 6.

3.3 Thermal Effects

3.3.1 Introduction

The effect of thermal radiation on explosives has been studied theoretically by McGuire and Law (1) and by Cook (2). Using different techniques and approximations both papers predict the temperature rise within an explosive that is shielded from the radiation by a thin slab of metal. Ignoring the effects of nuclear radiation from an atomic explosion, critical conditions are established under which the explosive will remain undamaged. These papers are summarised and compared below.

Experimental study is so far restricted to the tests conducted during Operation Buffalo (3). Little comparison with theory is possible owing to lack of data on the explosives used, and to the small radii of the shell.

3.3.2 Summary of paper by Cook (Reference 2)

Cook considered a pulse of high intensity thermal radiation incident on a target consisting of a steel plate covering a mass of high explosive. The radiation is partly absorbed at the steel surface and heat is conducted through the steel and into the explosive. It is assumed that the latter liberates heat according to the classical Arrhenius formula.

A radiation pulse of the form:-

$$\Phi(t) = Ct \exp(-\alpha t), \qquad (1)$$

was chosen, where C and α are constants. This function is the simplest analytical form exhibiting the correct qualitative features, though it ignores the radiation of extremely high intensity delivered from the weapon during the first few milliseconds. However, it is known that the thermal radiation delivered during this period is only about one or two per cent of the total. It was also assumed in this paper that loss of heat from the steel surface by convection or back radiation could be ignored.

Under these conditions the heat conduction equations were integrated on a digital computer to find the time to ignition, t_e, of the explosive, after the onset of the pulse. This time depends on the following parameters:

Heat of reaction	$= Q$ cals gm.$^{-1}$
Reaction rate	$= Z \exp(-E/RT)$ sec^{-1}
Thermal conductivities of steel and explosive	$= k_1, k_2$ cal cm^{-1} sec^{-1}($^{\circ}$C)$^{-1}$
Specific heats of steel and explosive	$= C_1, C_2$ cal.gm^{-1}($^{\circ}$C)$^{-1}$
Thermal diffusivities of steel and explosive	$= \kappa_1, \kappa_2$ cm.^{2} sec^{-1}

together with the constants C and α of equation (1), the steel thickness, d cms., and the initial temperature of the system, T_o $^{\circ}$C.

For a better understanding of the effect of these parameters on the ignition time, dimensionless variables were used, these being defined by the relations

$$\begin{aligned} \xi &= 10^{-7}\,(\rho_2 RQZ/k_2/)^{\frac{1}{2}} x = ax \\ \tau &= 10^{-14}(RQZ/C_2 E)\ t = bt, \qquad (2) \\ \theta &= (R/E)\ T = cT, \end{aligned}$$

where x, t, and T are distance from the steel surface, time, and temperature, respectively. The coefficients a, b, and c are shown for three explosives in the following table

Table 1

Explosive	RDX	Tetryl	NENO
a	1700	29.34	21.5
b	2770	0.83	0.21
10^4c	0.418	0.517	0.56

Further, the following quantities were defined,

$$\Gamma = Bc/a\ b\ k_1 \qquad (3)$$

$$\mu = \alpha/b \qquad (4)$$

$$\zeta_o = \left(K_2/K_1\right)^{\frac{1}{2}} a\ d \qquad (5)$$

where B is the product of the absorptivity coefficient of the steel surface with C.

The dimensionless ignition time, τ_c, then depends on the four parameters θ_o, Γ, μ, and ζ_o, which correspond physically to the initial temperature of the system, the constants C and α of equation (1), and the steel thickness d.

Two series of computations are reported in (2). In the first of these the general features of the behaviour of τ_c with respect to these parameters is examined and, in the second series, the case for which the explosive is RDX is examined in detail.

The results for the first series are shown graphically in Fig.1 where τ_c is plotted as a function of ζ_o, defined by equation (4), for various values of θ_o, Γ, and μ. The values of θ_o, Γ, and μ to which the curves labelled I - VII correspond are given in Table II.

Table II

Curve	θ_o	Γ	μ
I	0.0171	0.4964	14.0
II	0.0171	0.5433	14.0
III	0.0171	0.6641	14.0
IV	0.0171	0.0542	4.0
V	0.0151	0.0875	4.0
VI	0.0161	0.0875	4.0
VII	0.0171	0.0875	4.0

In this series, it was assumed that

$$\kappa_1 = 0.12 \text{ cm}^2 \text{ sec}^{-1} \qquad \kappa_2 = 0.006 \text{ cm}^2 \text{ sec}^{-1}$$
$$k_1 = 0.11 \text{ cal.sec}^{-1} \text{ cm}^{-1} (^\circ C)^{-1} \qquad k_2 = 0.0005 \text{ cal.sec}^{-1} \text{cm}^{-1} (^\circ C)^{-1}$$

The results obtained in the second series, in which the explosive is RDX, are shown in Fig.2, where the explosion ignition time is plotted against the steel thickness for values of the parameter B, listed in Table III. In all these results

$$\alpha = 2.078 \text{ sec.}^{-1}$$
$$T_o = 28.4\ ^\circ C.$$

Table III

Curve	B
I	565.4
II	621.3
III	737.7
IV	828.3
V	957.8
VI	1113.0

From the results of the first series of computations, shown in Fig.1, the following physical conclusions are drawn.

(i) For a given radiation pulse (C and α fixed), and for a given initial temperature, there exists a critical value of d, equal to d^*, say, such that, if the steel thickness exceeds d^*, there will be no explosion.

(ii) As far as the critical thickness is concerned, the shape of the radiation pulse is unimportant, the important quantity being the total radiation absorbed. This result also implies a critical minimum value of the total radiation for ignition to occur. Curves III and IV were plotted with the same value of Γ/μ^2, which is proportional to the total absorbed radiation, B/α^2. These curves have a common critical value of ζ_o, and hence of d.

In the case of tetryl, for which the coefficients a, b, and c are given in Table I, these value of θ_o correspond to 19°C, 38°C and 58°C. Thus for a 40° rise in the initial temperature the critical thickness is increased by about 20 or 25 percent. The two extremes of T_o, 19°C and 58°C, correspond roughly to room temperature and tropical storage temperature.

Returning to the specific example of RDX, the critical thickness of steel, d^*, may be obtained as a function of S as follows.

Table IV

B/α^2 (cal cm^{-2}	d^* (cm.)
258	1.07
222	0.925
192	0.80
171	0.71
144	0.595
131	0.545

These results are approximately linear but any extrapolation should be treated with caution. It is thus possible to determine the thickness of steel casing necessary to protect the explosive in a shell standing at a specified distance from the centre of the burst. As an example, suppose the radiation derives from a nominal 20 kiloton atomic weapon. Then the target for which d = 0.55cm., and the absorption coefficient is 0.6, is vulnerable to thermal radiation at a distance of 0.5 km., since the total incident thermal radiation on a clear day here is of the order of 203 cal cm^{-2}. The general conclusion which may be drawn from these results is that, if the target is sufficiently close to the burst to be vulnerable to thermal radiation, it would, in any case, suffer severe damage from the blast wave.

It is pointed out that, though the dimensionless solutions are accurate to within two percent, the parameters that are involved in the physical solutions are only approximate. For instance, to determine a value of d^* corresponding to a given critical dimensionless thickness, equations (2) and (5) are used to find the relation.

$$d^* = 10^7 \left(\frac{E\, C_2\, \kappa_1}{RQZ}\right)^{\frac{1}{2}} \zeta^*$$

Apart from the density, conductivity and specific heat of the explosive, the parameters are rather uncertain.

3.3.3 Summary of paper by McGuire and Law (Reference 1)

In the investigation conducted by McGuire and Law, a similar model was used to that described above. Additionally, heat loss by convection from the outer surface was incorporated, though heat arising from the chemical reaction of the explosive was neglected.

Four cases were considered: two with a steel container and two with brass. The total heat, S, delivered by the pulse, necessary to raise the metal/explosive interface 130°C and 70°C was determined for each container. The ambient temperature was assumed to be 30°C, and in each case the metal thickness was 0.318 cm. In particular the results in Table V apply to a propellant with thermal conductivity 5.5×10^{-4} cal.cm^{-1} sec^{-1} $(^{\circ}C)^{-1}$, density 1.5 gm cm^{-3}, and specific heat 0.35 cal. $gm^{-1}(^{\circ}C)^{-1}$.

Table V

Container	Quantity of heat ($cal.cm.^{-2}$)	
	Temperature = 160°C	Temperature = 100°C
Steel	39.4	21.2
Brass	35.4	19.2

The temperatures in Table V were chosen because a propellant ignites at 160°C or is rendered useless at 100°C. An example of a temperature-time curve is shown in Figure 3.

The accuracy of this method is quoted as two per cent provided the minimum radius of curvature of the container is 2 in. The computations were repeated while neglecting the heat loss from the outer surface and it was found that the temperature-time curves were left substantially the same. This justifies Cook's assumption mentioned in the first paragraph of 3.3.2 above.

Because chemical reaction is neglected within the explosive, the temperatures in Table V and figure 3 are proportional to the intensity of the pulse. The results also apply to any material with the same physical properties as the propellant considered.

The explosive RDX, considered in detail in Cook's report, has roughly the required properties and initial temperature, so that the two methods may be compared.

From figure 2 it appears that a pulse of 130.94 $cal.cm^{-2}$ incident on steel of thickness 0.315 cm causes ignition of RDX after 1.6 sec. Scaling the results of figure 3 to apply to a similar pulse it is found that the interface has the ignition temperature of RDX after approximately 0.8 sec. Thus the first method gives an ignition time of about twice the value of that given by the second method.

It is not thought that such an error could be explained by the small differences of the thermal properties used in each method, especially since the assumptions (e.g. the neglect of a chemical reaction and of heat loss from the surface) tend to keep the results in closer agreement.

3.3.4 Results from Operation Buffalo (Reference 3)

Little comparison is possible between the experiments conducted in Operation Buffalo and the above theories. This is partly due to the lack of reliable data on the explosives used, but also because the inner radius of the cases was only 2.86 cm., which is outside the limit for reasonable accuracy set by the theories. It is to be expected, then, that the ignition times predicted by theory will be considerably smaller than realised in the experiments.

In one instance, (Case No.77 reference (3)), a shell containing an RDX beeswax mixture was exposed to a total incident radiation of 425 cal cm^{-2}. The container was made of steel of thickness 0.635 cm., and this protected the explosive from all damage. Assuming an absorption coefficient of 0.6, the total absorbed radiation would be 255 $cal.cm^{-2}$. From Cook's results it may be estimated that this radiation would cause ignition of RDX, after approximately 2.5 sec. and that for no damage to occur the steel would have to be 0.9 cm thick.

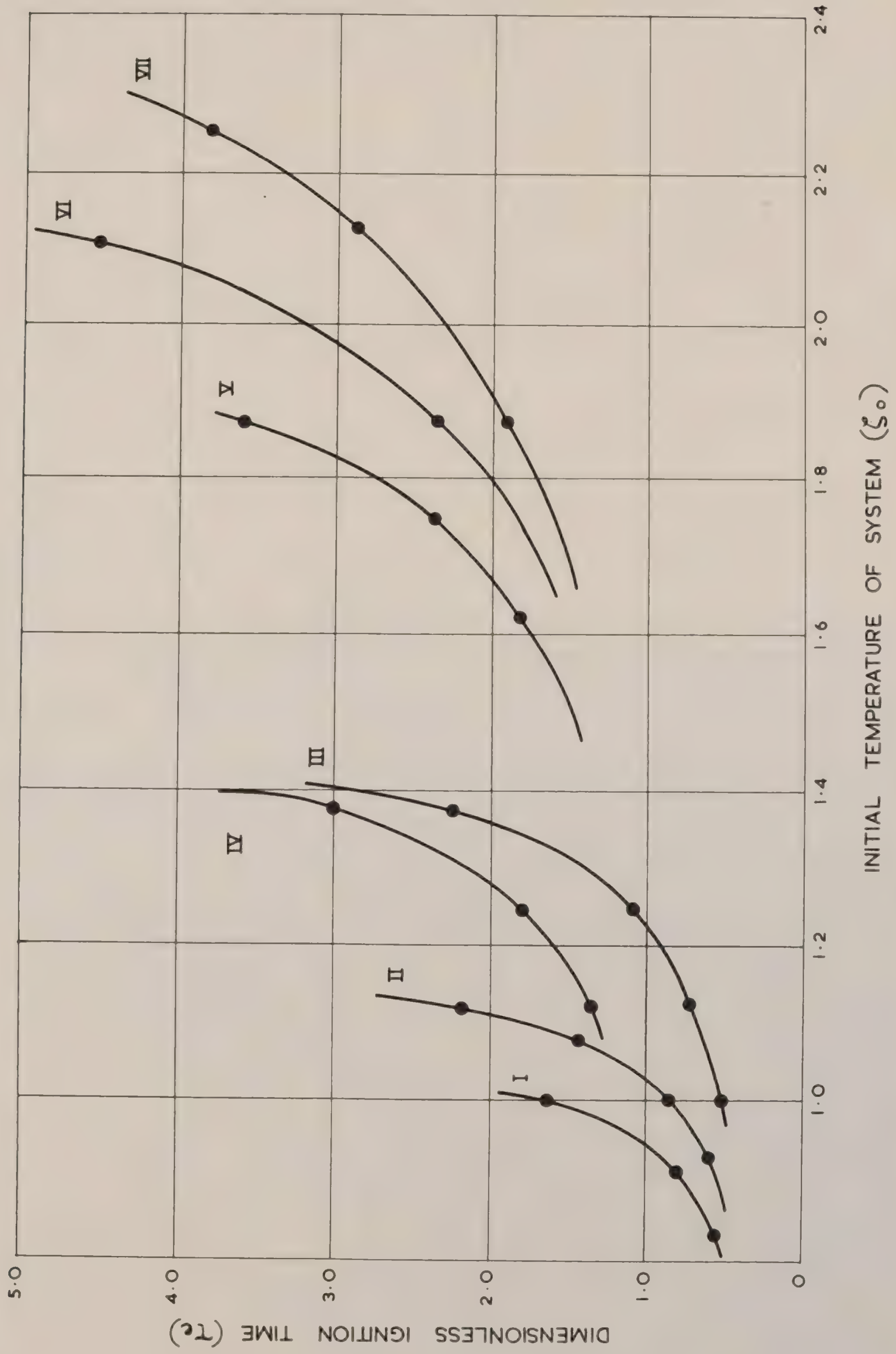
Other experiments in Operation Buffalo show no damage to the explosive even if the steel thickness is as low as 0.159 cm. but comparison is not possible since these results are outside the scope of Cook's computations.

References

1. J. H. McGuire and M. Law, DSIR, Fire Research Station, S.R. Note No.22/1955. "The temperature rise of a propellant in a metal case computed by the electrical analogue of heat conduction."

2. G. B. Cook, ARDE Report(B) 23/56. "The theory of thermal explosions: the initiation of explosion by a pulse of high intensity thermal radiation."

3. AWRE Report (to be published) Operation Buffalo, Explosives Group Final Repot, Part 7.



DEPENDENCE OF IGNITION TIME ON INITIAL SYSTEM TEMPERATURE

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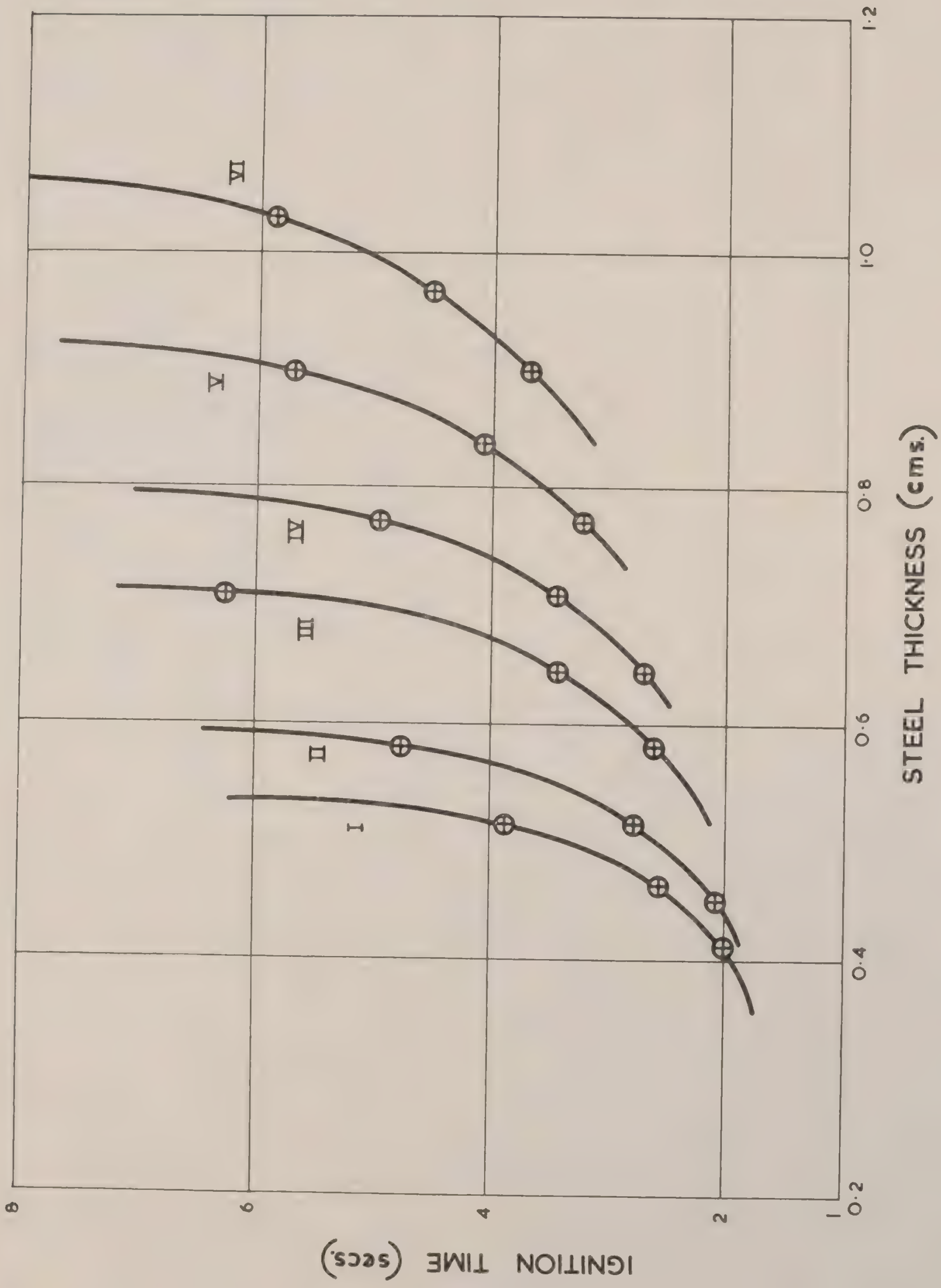

IGNITION TIME VS. STEEL THICKNESS FOR SEVERAL RADIATION PULSES (RDX.)

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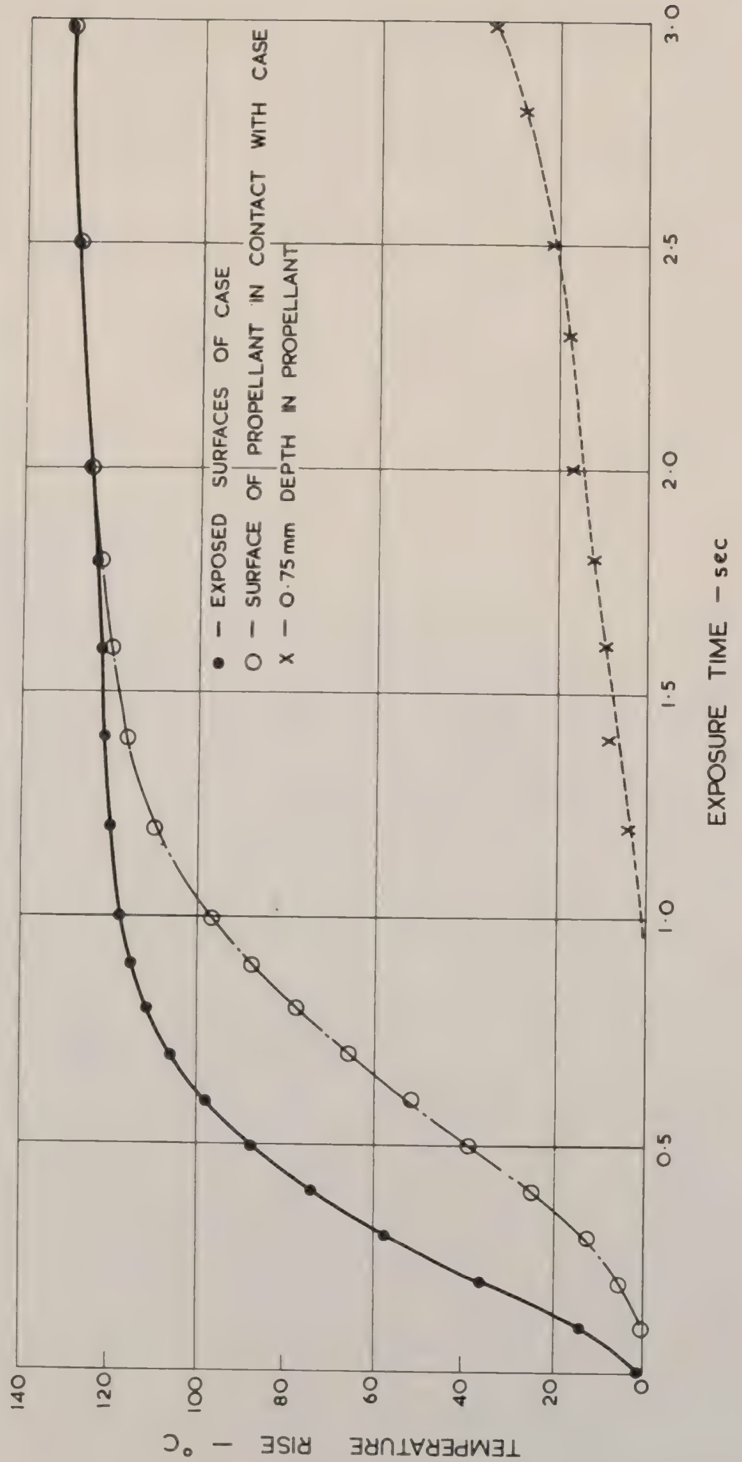

TEMPERATURE RISE OF PROPELLANT AND STEEL CASE
(39·4 cal/cm² incident)

3.4 Nuclear Radiation Effects

3.4.1 Absorption of nuclear radiation by explosives

(a) Absorption of gamma rays

An atomic explosion produces several different types of nuclear radiation. These are fission fragments, alpha particles, beta particles, neutrons and gamma rays. Only neutrons and gamma rays have a long range and are likely to be present in significant concentrations at even short distances from the centre of the explosion. Therefore only gamma rays and neutrons will be considered. The primary effect of gamma rays on explosives will be the same as their effect on other substances. A gamma ray photon loses its energy over a long path by interaction with the electrons of the atoms forming the explosive and these electrons will be left in specially energetic states. Some of these primary electrons may be given sufficient energy to react with other electrons. Some of the photon energy will be given up as heat, and this will be dissipated through the solid with great rapidity. In explosives, as a result of these effects decomposition will be produced along the path of each photon.

(b) Absorption of neutrons

Fast neutrons will lose their kinetic energy by collision with the nuclei of the atoms forming the explosive. A neutron may penetrate a considerable distance before suffering an interaction but at each interaction it will lose a large fraction of its energy, up to a maximum of a half for an interaction with a hydrogen atom. The atomic nucleus will receive this kinetic energy and will fly out of its normal position in the explosive. It will then lose this energy rapidly in a very short path by exciting electrons of other atoms, and as heat. Again, in explosives the passage of a fast neutron will cause decomposition to occur along its path. The decomposition, however, instead of being spread fairly evenly along the path, as in the case of gamma rays, will be concentrated in particular regions.

Thermal neutrons are moving so slowly that they have no kinetic energy to give up and they only produce an effect in an explosive if they are capable of undergoing a nuclear reaction with the atomic nuclei of the explosive. One such reaction, of particular interest in explosive science is the (n, p) reaction with nitrogen, i.e. $n + {}^{14}N \rightarrow {}^{14}C + p$. Here a proton of high energy (0.61 MeV) is produced. This will lose its energy very rapidly giving a concentrated region of decomposition. Another thermal neutron nuclear reaction is with the hydrogen nucleus when a high energy gamma ray photon (2.2 MeV) is produced.

(c) Energy deposition

In general only a fraction of the total radiation incident on an explosive charge is absorbed by the charge. The rest is carried by the fraction of the incident radiation that goes straight through the charge. The energy of the absorbed radiation is transferred to the explosive, and in the case of thermal neutrons the energy produced by nuclear reactions, e.g. the (n, p) nitrogen reaction, can be considered as additional energy transferred to the explosive. The "energy deposition" produced in a particular explosive by irradiation with a particular radiation can be calculated and this is found to be the best general factor to use in a quantitative assessment of the effects of nuclear irradiation on explosives. This does not mean that for the same energy deposition gamma ray irradiation and neutron irradiation will always give quantitatively equivalent effects;

for a given energy deposition, bomb neutrons are thought to be 1.7 times as effective as gamma radiation in producing physiological effects in animals (1), and similar differences are sometimes found with explosives.

3.4.2 Effect of irradiation on explosives

(a) Possibility of immediate explosion

The absorption of a nuclear particle by an explosive as noted above, gives a region in which a transient high temperature is produced and decomposition takes place. This decomposition liberates chemical energy which tends to maintain the high temperature and this will in itself encourage further decomposition. If more energy is produced in this region than can be dissipated, e.g. by thermal conduction, decomposition will continue in the "hot spot" at an accelerating rate and the "hot spot" will grow rapidly leading to an explosion. It is conceivable therefore that absorption of a single nuclear particle by an explosive charge could lead to an explosion. However, it has been shown experimentally (2) that spherical "hot spots" of size less than 10^{-3} to 10^{-5} cms. (these were produced by means other than nuclear irradiation), are quenched by heat losses and do not grow to give explosion. The "hot spots" produced by nuclear irradiation are at least an order smaller in size than this, and other experiments (3) have shown directly that the region of decomposition produced by a single nuclear particle is too small and the high temperature is maintained for too short a time for growth to explosion to occur in any useful explosive. Even fission of a uranium atom embedded in an explosive, will not of itself give detonation (11). An immediate explosion can, therefore, only be produced by the aggregate effect of the absorption of a large number of particles, giving sufficient energy liberation in a particular region to constitute an effective hot spot.

Work on the initiation of silver azide by visible and ultra-violet light irradiation and by electron bombardment (4) has shown that explosions occur only when the absorption of radiant energy is so great that a marked rise in the temperature of the explosive is produced. A similar effect is to be expected with nuclear irradiation, and energy depositions of the order of 10^8 ergs. per gram, delivered in so short a time that heat dissipation processes are unimportant, are probably necessary to produce immediate explosion in initiators. For high explosives and propellants it is probable that an energy deposition an order greater would be required. No direct measurements have been reported and the estimated values given here may be an order wrong either way.

(b) Effect of irradiation on the power of explosives

The next four sub-sections (b), (c), (d), (e), will consider permanent changes produced in explosives, which may affect their performance some long time after the irradiation has ceased. For all these permanent effects the evidence indicates that it is the total energy deposition which is important; whether it is absorbed rapidly or slowly, continuously or intermittently does not matter. The power of an explosive will be reduced proportionally to the fraction of the explosive decomposed by the irradiation. It is known that ionisation of air by nuclear irradiation requires an average energy of about 30 ev and other similar processes in solids take from 10 to 30 ev (5). A moderate reduction in the power of lead azide, say five per cent, should therefore be produced by an energy deposition of about 10^{10} ergs per gram. An American report (6) describes the irradiation of several explosives with the 0.41 Mev gamma irradiation from a gold source. 52 days irradiation of lead azide, corresponding to an

energy deposition of 10^{10} ergs per gram gave 4% decomposition, confirming the above estimate. For the same energy deposition the decomposition of R.D.X. and T.N.T. were respectively about 20% and 1% of the lead azide value. Lead styphnate had a very low decomposition rate (approximately that of T.N.T.) but nitroglycerine was rather higher even than lead azide. Mercury fulminate had a 30% decomposition after only half the standard dosage and lost most of its power. The latter is therefore particularly sensitive to irradiation, which is not unexpected in view of its known instability. It may be noted that except for mercury fulminate, the liberation of chemical energy from the small amount of decomposition is less than $1/_{10}$th of that absorbed from the nuclear radiation. In these decompositions the activation energy is supplied directly by the radiation and the temperature coefficient is therefore small e.g. the decomposition of lead azide was increased about five times only by raising the temperature from -40 to + 71°C.

(c) Effect of irradiation on the sensitivity of explosives

Permanent changes in the sensitivity of explosives are important because an increase in sensitivity may make them unsafe for handling and a decrease in sensitivity may adversely affect their functioning. The sensitivity of an explosive should be increased by nuclear irradiation, because of the resulting decomposition and the autocatalytic effect. At very high dosages the sensitivity may fall again and in any case the loss of power resulting from the decomposition will become the dominant effect. The effect of nuclear radiation on the sensitivity of initiators is discussed in detail in a report (7) describing the effect of irradiation with high energy x-rays on the thermal explosion of Service lead azide. Later work (8) shows that slight changes are produced in the decomposition characteristics of lead azide by irradiation at an energy deposition as low as 10^6 ergs./g. An impact test however showed sensitization only at doses of about 10^9 ergs./g. and even at this level a friction test, capable of clearly differentiating Service lead azide and pure lead azide, showed no sensitization. Pile radiation, for which the energy deposition comes in roughly equal parts from gamma radiation and thermal neutrons, gave exactly similar effects for the same energy deposition. Quantitatively similar results for gamma and pile irradiation and impact and stab sensitivity tests are described in American reports (6,9). It has already been noted that lead styphnate is resistant to gamma radiation and no change in impact sensitiveness was produced by doses up to 10^9 ergs./g., nor was the character of subsequent thermal decompositions changed. Pile irradiation (10) at doses of this order again gave negligible decomposition, but subsequent thermal decomposition characteristics were markedly changed. This is probably the most striking example to date of different effects being produced by gamma and neutron irradiation. For high explosives and propellants similar results are obtained (6), the more sensitive materials (e.g. nitroglycerine, R.D.X.) showing effects at energy depositions of 10^9 ergs./g. and above. In general, changes in sensitivity are found in some explosives at energy depositions of about 10^9 ergs./g. and no significant effect would be expected at energy depositions less than 10^8 ergs./g.

(d) Effect of irradiation on the stability of explosives

It has been noted that the partial decomposition of an explosive produced by nuclear irradiation, because of the autocatalytic effect, could in theory give a reduction in the stability of the explosive. The process may be similar to the increase of sensitivity discussed under (c) above. It is to be expected that an appreciable decrease in stability would be produced by an energy deposition of the same order as that which gave an appreciable increase in its sensitivity, i.e. greater than 10^8 ergs per

gram. It should be noted that this effect will be most important for explosives that inherently do not have good stability. If a particular explosive's stability is such that it has a useful life of one year, absorption of sufficient nuclear radiation to reduce the useful life to one tenth may be significant. For another more stable explosive, say with a useful life of a hundred years, reduction of its useful life to one tenth would probably not matter. The best estimate that can be given is that an energy deposition of greater than 10^8 ergs. per gram may cause a substantial fractional change in the stability. Whether or not this would have any practical effect for any particular explosive is doubtful.

(c) Effect of irradiation on the physical properties of explosives

In general a small change in the physical properties of an explosive will not seriously affect its functioning. However, in special cases e.g. with propellants, changes in hardness etc. may be important. There has been considerable work on inert plastics and it is known that the effect of irradiation is to split chemical bonds and produce cross-linkages with a consequent increase in the average molecular weight of the material. This increases viscosity, hardness etc. A. Charlesby reports (8) that an energy deposition of 7.4×10^9 ergs./gram gives 1 per cent linking of carbon atoms in perspex. An energy deposition of about 10^{10} ergs./gram is probably required to produce a significant change in the physical properties of explosives.

3.4.3 Energy deposition in typical explosives

It has been stated above that energy deposition is the best factor to use in a quantitative assessment of the effects of nuclear irradiation on explosives. The energy depositions in lead azide and T.N.T. for various types of irradiation have been calculated and are summarised in Tables I and II. The values given are only approximate and no corrections have been made for "bad geometry." The energy depositions in other high explosives and propellants containing carbon, hydrogen, nitrogen and oxygen only, will probably be insignificantly different from the T.N.T. values and the lead azide values will probably be approximately correct for other initiators which are salts of heavy metals.

Table I

Energy deposition in lead azide and T.N.T. Due to gamma irradiation

gamma energy	Energy deposition in ergs per gram per roentgen	
(Mev)	lead azide	T.N.T.
0.5	75	123
2.0	74	124
5.0	103	125
10.0	151	124

Table II

Energy deposition in lead azide and T.N.T. due to thermal neutrons

Invident neutron flux	Energy deposition in ergs per gram	
per cm^2	lead azide	T.N.T.
10^9	21	14
10^{12}	2.1×10^4	1.4×10^4
10^{16}	2.1×10^8	1.4×10^8

The energy deposition from thermal neutrons is almost entirely due to the nitrogen content of the materials by the (n, p) reaction mentioned above. The energy deposition per gram of nitrogen by this reaction is 7.4×10^{-8} ergs. for unit incident neutron flux per cm^2.

Table III

Energy deposition in lead azide and T.N.T. due to fast neutrons

For these calculations it has been assumed that each neutron suffering an interaction with a target nucleus gives up all its energy to the target.

Incident neutron energy	Energy deposition in ergs per gram per neutron: lead azide	T.N.T.
100,000 ev.	1×10^{-8}	6×10^{-8}
1 Mev	6×10^{-8}	4×10^{-7}
10 Mev	5×10^{-7}	1×10^{-6}

Table IV

Estimated energy depositions to produce particular effects in lead azide and T.N.T.

Effect	Energy deposition in ergs/gram	
	lead azide	T.N.T.
Immediate explosion	10^8	10^8
Decrease in power	10^{10}	10^{10}
Increase in sensitivity	10^8	10^9
Decrease in stability	10^9	10^9

Table V

Neutron and gamma doses to give energy deposition of 10^8 ergs per gram in lead azide and 10^9 ergs per gram in T.N.T.

Type of radiation	Dose	
	lead azide	T.N.T.
gamma rays	10^6 roentgens	10^7 roentgens
Thermal neutrons	5×10^{17} per sq.cm.	5×10^{18} per sq.cm.
1 Mev neutrons	2×10^{15} " " "	2×10^{15} " " "
10 Mev neutrons	2×10^{14} " " "	10^{15} " " "

For mixed irradiation the effects are additive.

3.4.4 General conclusions

On theoretical grounds it is to be expected that nuclear irradiation will change the properties of initiators, high explosives and propellants. The experimental evidence supports this view, and necessarily crude estimates indicate that at energy depositions greater than 10^8 ergs per

gram for initiators, and 10^9 ergs per gram for high explosives and propellants, there is a possibility of (a) immediate explosion and (b) if (a) does not occur, increased sensitivity and decreased stability. The dosages of gamma radiation, thermal neutrons and fast neutrons needed to give this energy deposition are summarised in Table V.

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T 49/57
Downgraded April
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Y. McA.

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ES5/185

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

UK true land surface burst Buffalo-2, Maralinga

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 49/57

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OPERATION BUFFALO

The Radiation Survey of Ground Deposited Radioactivity

J. J Rae

DECLASSIFIED FOR
BY AWE ALDERMASTON

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R. E. S.	✓
INV.	✓
AUTHOR	✓
SUBJECT	✓

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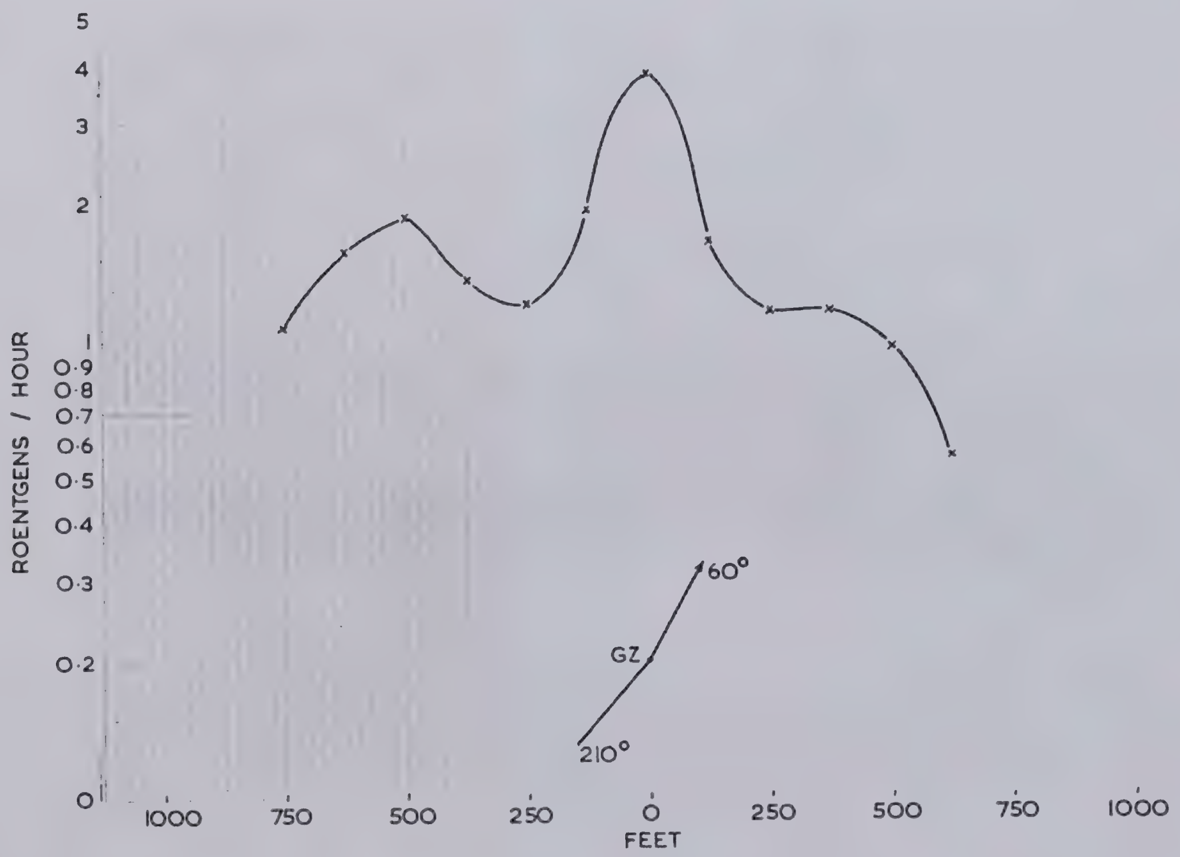
A.W.R.E.,
Aldermaston, Berks.

August, 1957



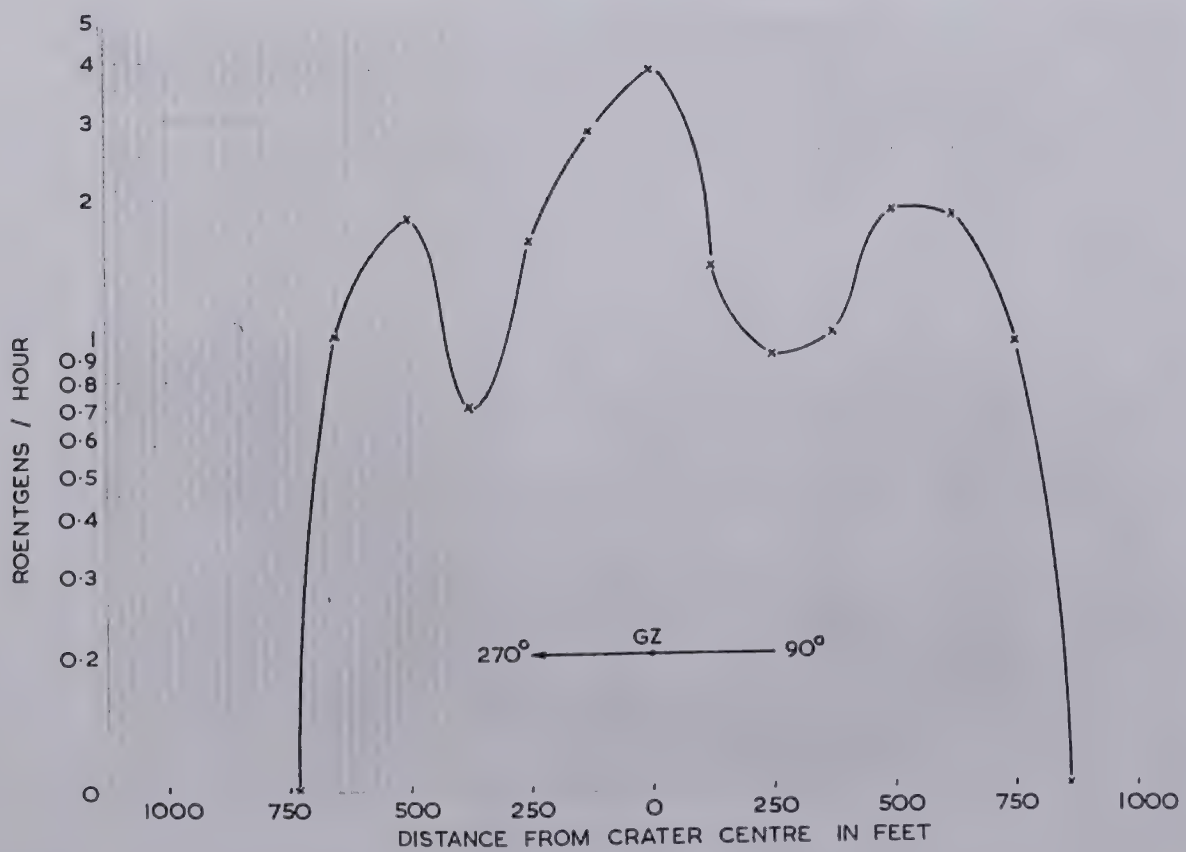
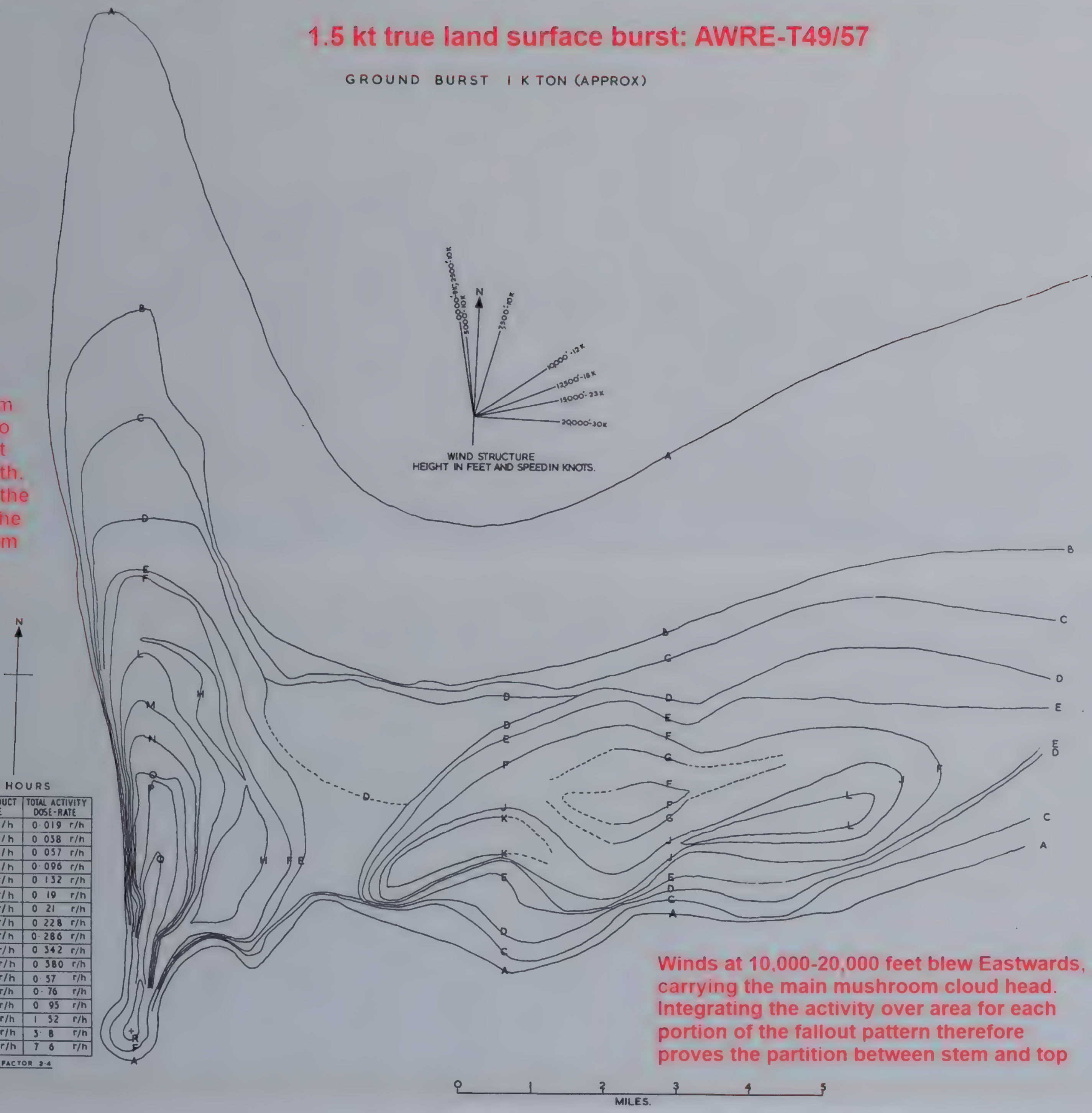


FIGURE 6 BUFFALO ROUND I. CRATER SURVEY GAMMA DOSE RATES

1.5 kt true land surface burst: AWRE-T49/57

GROUND BURST 1 K TON (APPROX)



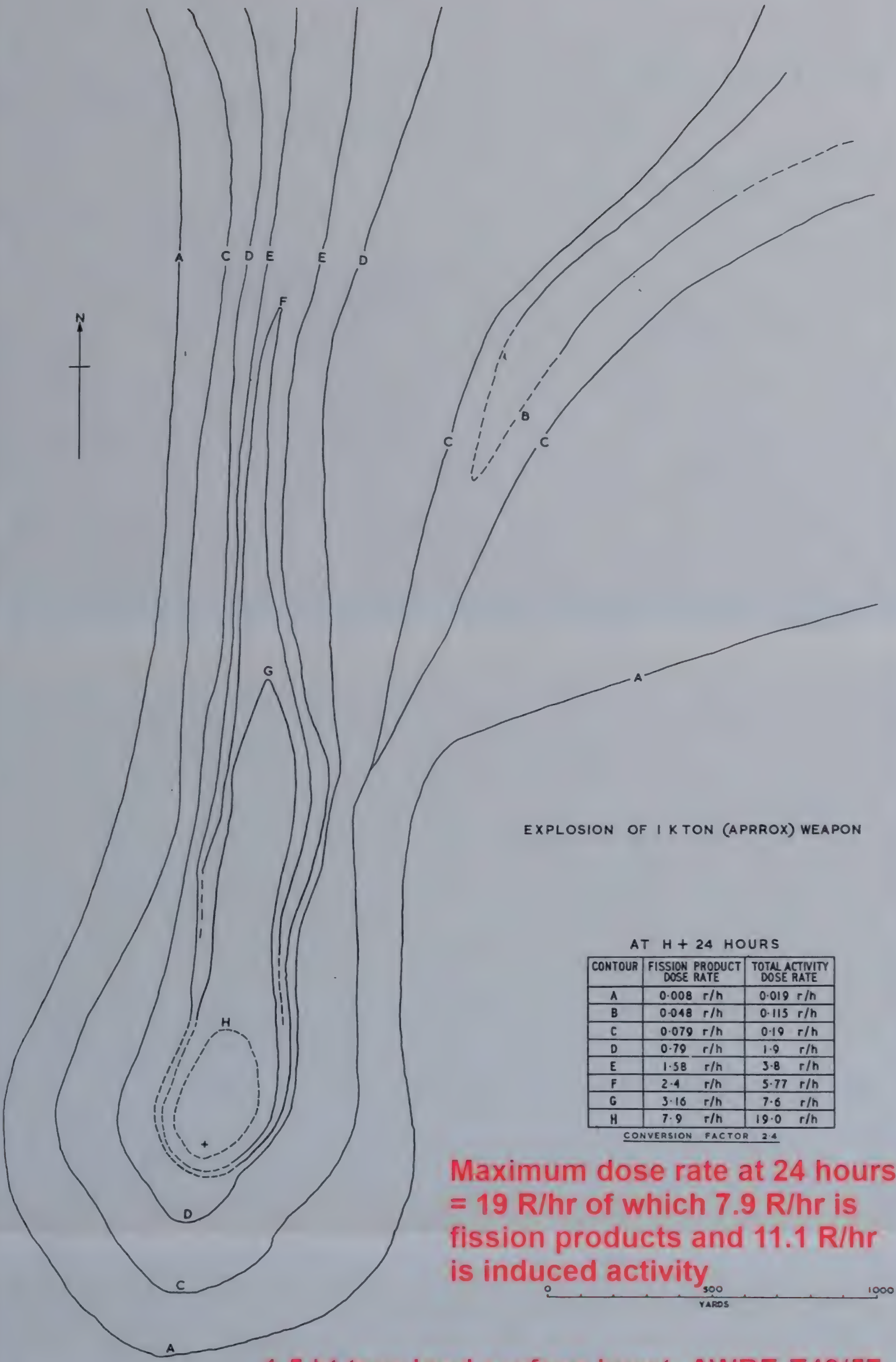
AT H + 24 HOURS

CONTOUR	FISSION PRODUCT DOSE-RATE	TOTAL ACTIVITY DOSE-RATE
A	0·008 r/h	0·019 r/h
B	0 016 r/h	0 038 r/h
C	0·024 r/h	0 057 r/h
D	0·040 r/h	0·096 r/h
E	0 055 r/h	0 132 r/h
F	0·079 r/h	0 19 r/h
G	0·087 r/h	0 21 r/h
H	0 095 r/h	0 228 r/h
J	0 119 r/h	0·286 r/h
K	0·142 r/h	0 342 r/h
L	0·158 r/h	0 380 r/h
M	0·237 r/h	0·57 r/h
N	0 316 r/h	0·76 r/h
O	0 395 r/h	0 95 r/h
P	0·632 r/h	1 52 r/h
Q	1·58 r/h	3·8 r/h
R	3 16 r/h	7 6 r/h

CONVERSION FACTOR 2·4

FIGURE 7. BUFFALO ROUND 2. GAMMA DOSE RATE CONTOURS

Marcoo



AT H + 24 HOURS

CONTOUR	FISSION PRODUCT DOSE RATE	TOTAL ACTIVITY DOSE RATE
A	0·008 r/h	0·019 r/h
B	0·048 r/h	0·115 r/h
C	0·079 r/h	0·19 r/h
D	0·79 r/h	1·9 r/h
E	1·58 r/h	3·8 r/h
F	2·4 r/h	5·77 r/h
G	3·16 r/h	7·6 r/h
H	7·9 r/h	19·0 r/h

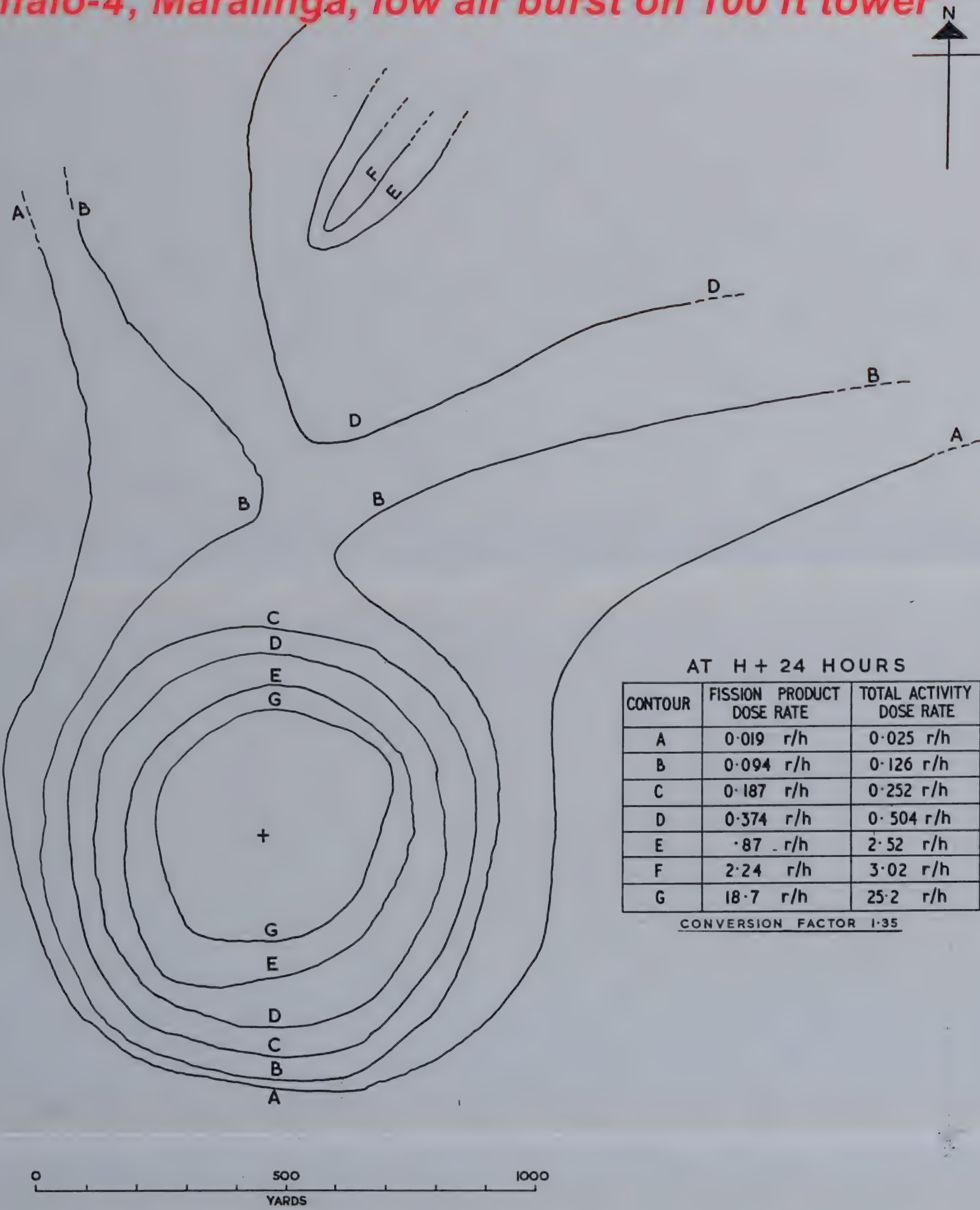
CONVERSION FACTOR 2·4

Maximum dose rate at 24 hours = 19 R/hr of which 7.9 R/hr is fission products and 11.1 R/hr is induced activity

1.5 kt true land surface burst: AWRE-T49/57

FIGURE 8. BUFFALO ROUND 2 GAMMA DOSE RATE CONTOURS – CRATER REGION

Buffalo-4, Maralinga, low air burst on 100 ft tower



AT H + 24 HOURS

CONTOUR	FISSION PRODUCT DOSE RATE	TOTAL ACTIVITY DOSE RATE
A	0·019 r/h	0·025 r/h
B	0·094 r/h	0·126 r/h
C	0·187 r/h	0·252 r/h
D	0·374 r/h	0·504 r/h
E	·87 r/h	2·52 r/h
F	2·24 r/h	3·02 r/h
G	18·7 r/h	25·2 r/h

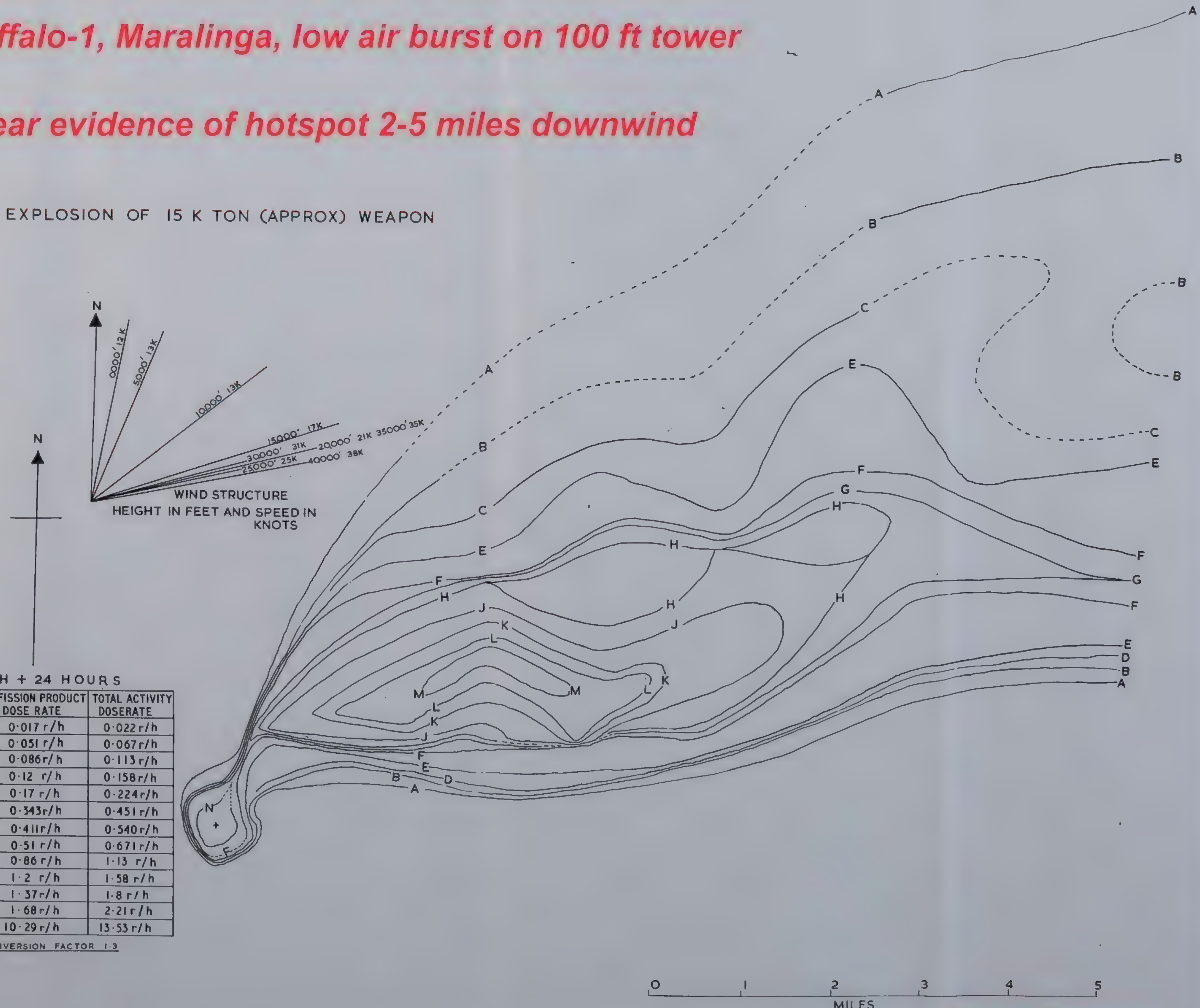
CONVERSION FACTOR 1·35

FIGURE 10. BUFFALO ROUND 4 GAMMA DOSE RATE CONTOURS — CRATER REGION

Buffalo-1, Maralinga, low air burst on 100 ft tower

Clear evidence of hotspot 2-5 miles downwind

EXPLOSION OF 15 K TON (APPROX) WEAPON



AT H + 24 HOURS

CONTOUR	FISSION PRODUCT DOSE RATE	TOTAL ACTIVITY DOSERATE
A	0·017 r/h	0·022 r/h
B	0·051 r/h	0·067 r/h
C	0·086 r/h	0·113 r/h
D	0·12 r/h	0·158 r/h
E	0·17 r/h	0·224 r/h
F	0·343 r/h	0·451 r/h
G	0·411 r/h	0·540 r/h
H	0·51 r/h	0·671 r/h
J	0·86 r/h	1·13 r/h
K	1·2 r/h	1·58 r/h
L	1·37 r/h	1·8 r/h
M	1·68 r/h	2·21 r/h
N	10·29 r/h	13·53 r/h

CONVERSION FACTOR 1·3

FIGURE 4. BUFFALO ROUND I. GAMMA DOSE RATE CONTOURS.

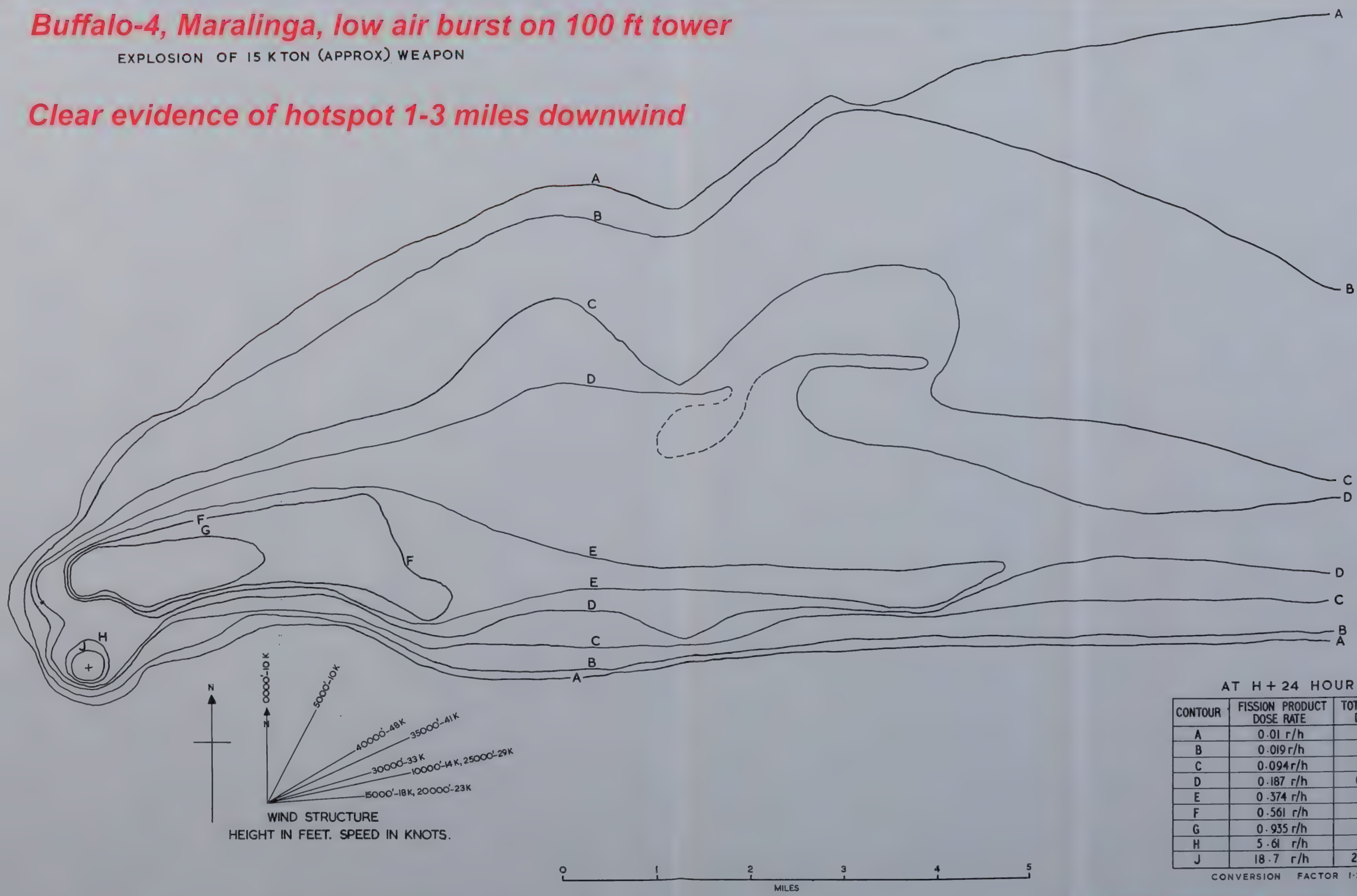
One Tree

UK Atomic Weapons Research Establishment Report: AWRE-T49/57

Buffalo-4, Maralinga, low air burst on 100 ft tower

EXPLOSION OF 15 KTON (APPROX) WEAPON

Clear evidence of hotspot 1-3 miles downwind



AT H + 24 HOURS

CONTOUR	FISSION PRODUCT DOSE RATE	TOTAL ACTIVITY DOSE RATE
A	0.01 r/h	0.013 r/h
B	0.019 r/h	0.025 r/h
C	0.094 r/h	0.126 r/h
D	0.187 r/h	0.252 r/h
E	0.374 r/h	0.504 r/h
F	0.561 r/h	0.755 r/h
G	0.935 r/h	1.26 r/h
H	5.61 r/h	7.55 r/h
J	18.7 r/h	25.2 r/h

CONVERSION FACTOR 1.35

FIGURE 9 BUFFALO ROUND 4 GAMMA DOSE RATE CONTOURS

breakaway

Atomic Weapons Research Establishment report AWRE-T49/57

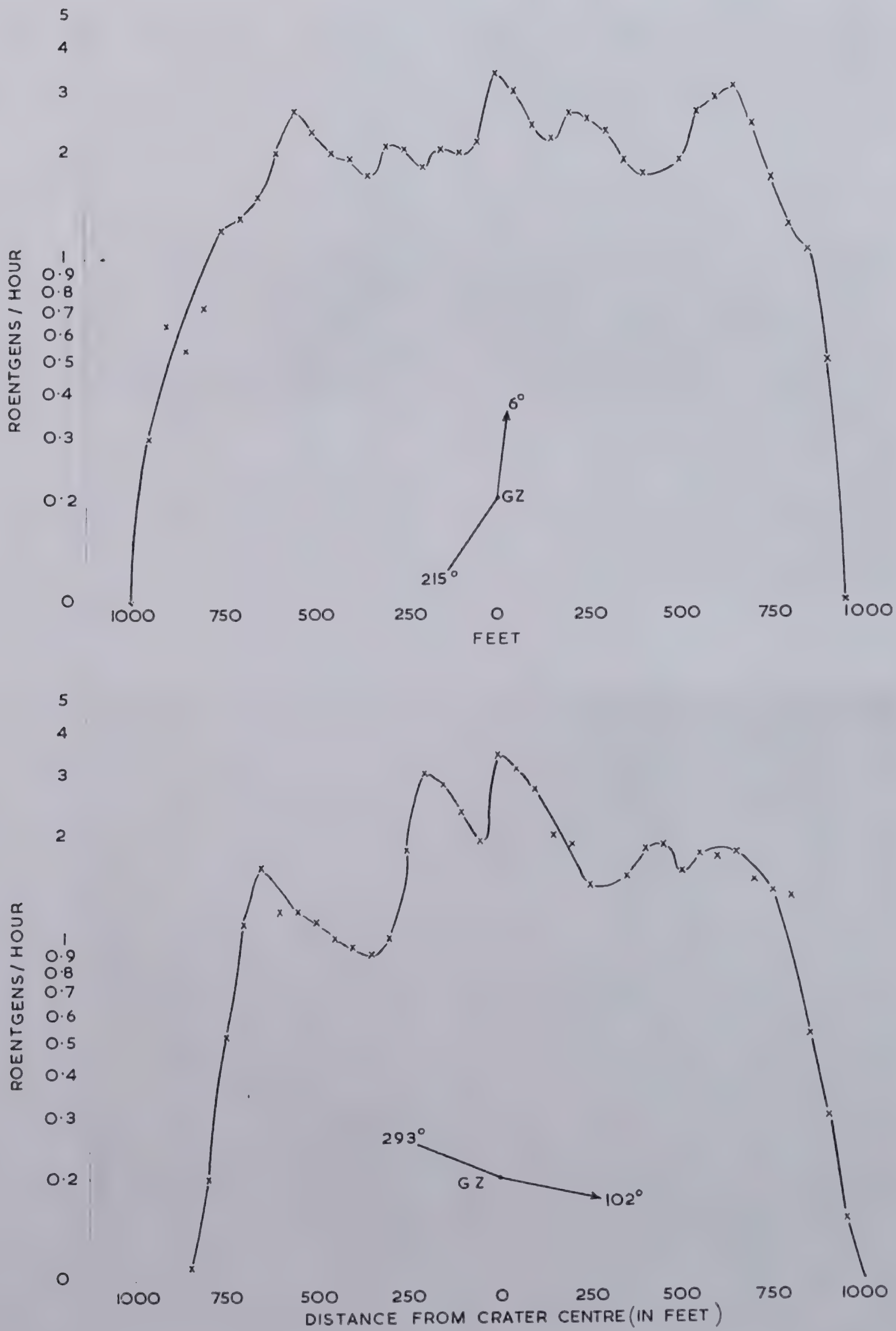


FIGURE 11 BUFFALO ROUND 4. CRATER SURVEY GAMMA DOSE RATES

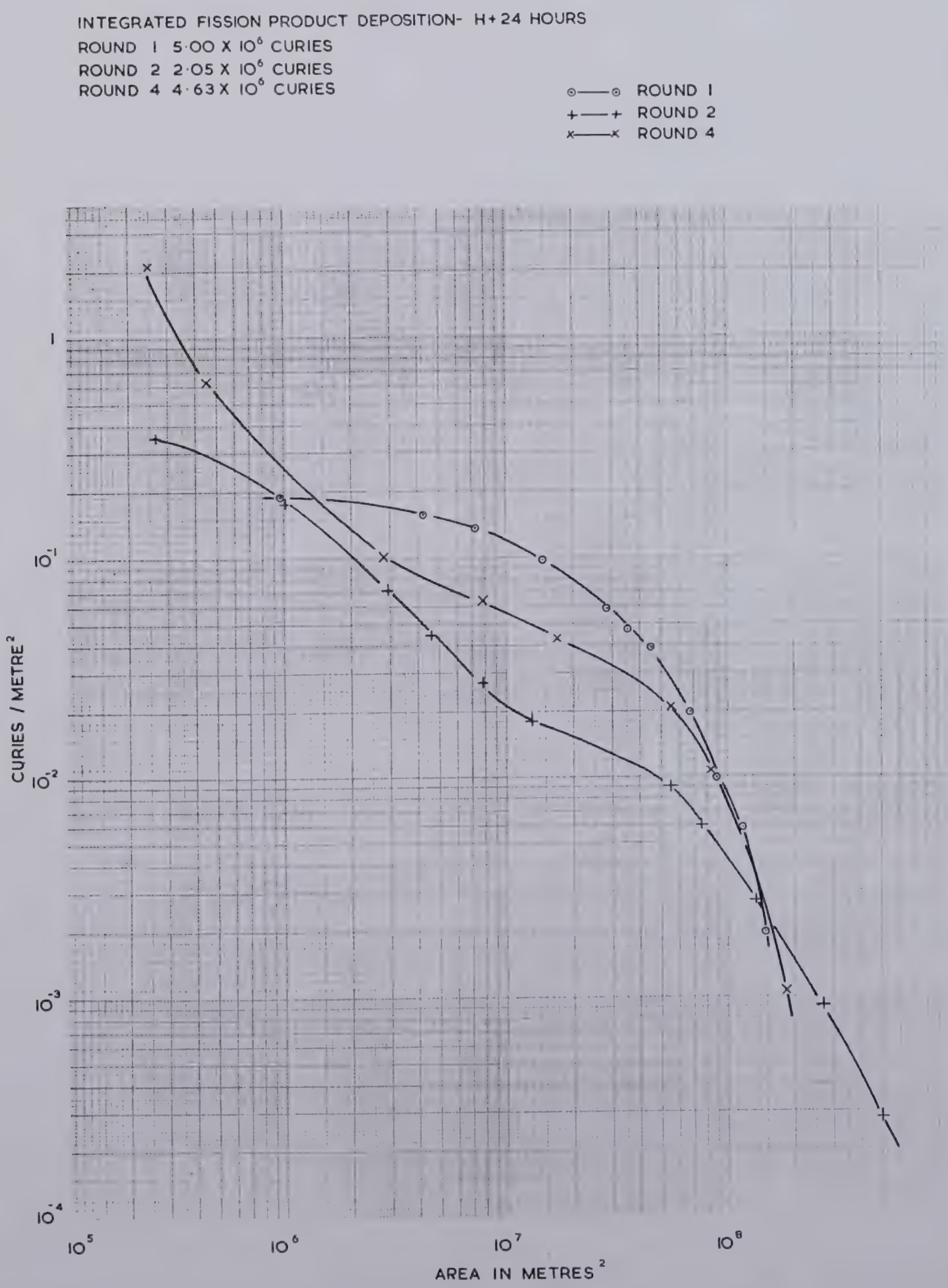


FIGURE 12 ROUNDS 1, 2, & 4. INTEGRATED FISSION PRODUCT DEPOSITION – H+24 HOURS

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12 PAGES.

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

DECLASSIFIED FOR PR[illegible]
BY AWE ALDERMASTO[illegible]

REPORT No. T 9/55

BB005

OPERATION TOTEM

Radiation Surveys of Totem Craters

J. J. Rae

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Mr J J Rae

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[redacted]

A.W.R.E.,
Aldermaston. Berks.

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October, 1955.

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United Kingdom Atomic Energy Authority

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT T9/55

Radiation Surveys of Totem Craters

J. J. Rae

Summary

The craters of the two Totem weapons were re-visited after 630 days and a careful survey made of the residual activity. At the same time soil and vegetation samples were collected.

The results of the survey are compared with those made at D + 9 days.

7. As a matter of interest spot checks were made on numerous pieces of loose metal, e.g. girders, gear wheels, electric motors, which were scattered indiscriminately in both crater areas and were presumably part of the original towers. Readings were made both close to the surface of these specimens and at 1 metre distant using a 1313 monitor and several readings in mr per hour are tabulated below.

Crater	Near Surface	1 metre distant	
T1	29	15	
T1	80	20	
T1	60	21.5	
T1	120	21	
T1	700	38.5	18" square plate 25 yards in general direction OE
T1	70	10	
T2	70	10	
T2	600	75	Gear wheel 3 ft. diameter between OD and OE, 45 yards from the centre
T2	100	32	One of the four square tower base plates.

The above figures were obtained off purely random samples of debris, and it is interesting that from only one of the tower base plates was a high reading obtained, the others showing no significant increase over the surrounding level.

8. To obtain a representative sample of crater soil an area 2 metres square was marked out on a reasonable flat part of the crater of Totem 1 and the surface layer of earth collected. Improvised containers were made out of two galvanized iron dustbins no other clean containers being available. For this operation full protective clothing including respirators was worn and care was taken to seal and wire down the bin lids to prevent the spread of radioactive dust. Thus dose reading at 1 metre above the sample area just before collection was 11.5 mr per hour and the distance and direction of the sample area from the centre was 8 yds. along OH. The total weight of earth collected was about 400 pounds.

Smaller samples of vegetation and soil, both surface and 5" deep were collected at known intervals up to 8 miles down the fall-out area of Totem 1. Owing to the terrain it was not possible to collect as many samples of grass as was hoped, but representative samples of herbage and soil were collected and packed in polythene bags.

9. Previous surveys of these two craters had been made on D + 9 days. Comparisons on an arbitrary scale, of measurements made along the same diameter are shown in Figs 9.1 and 9.2.

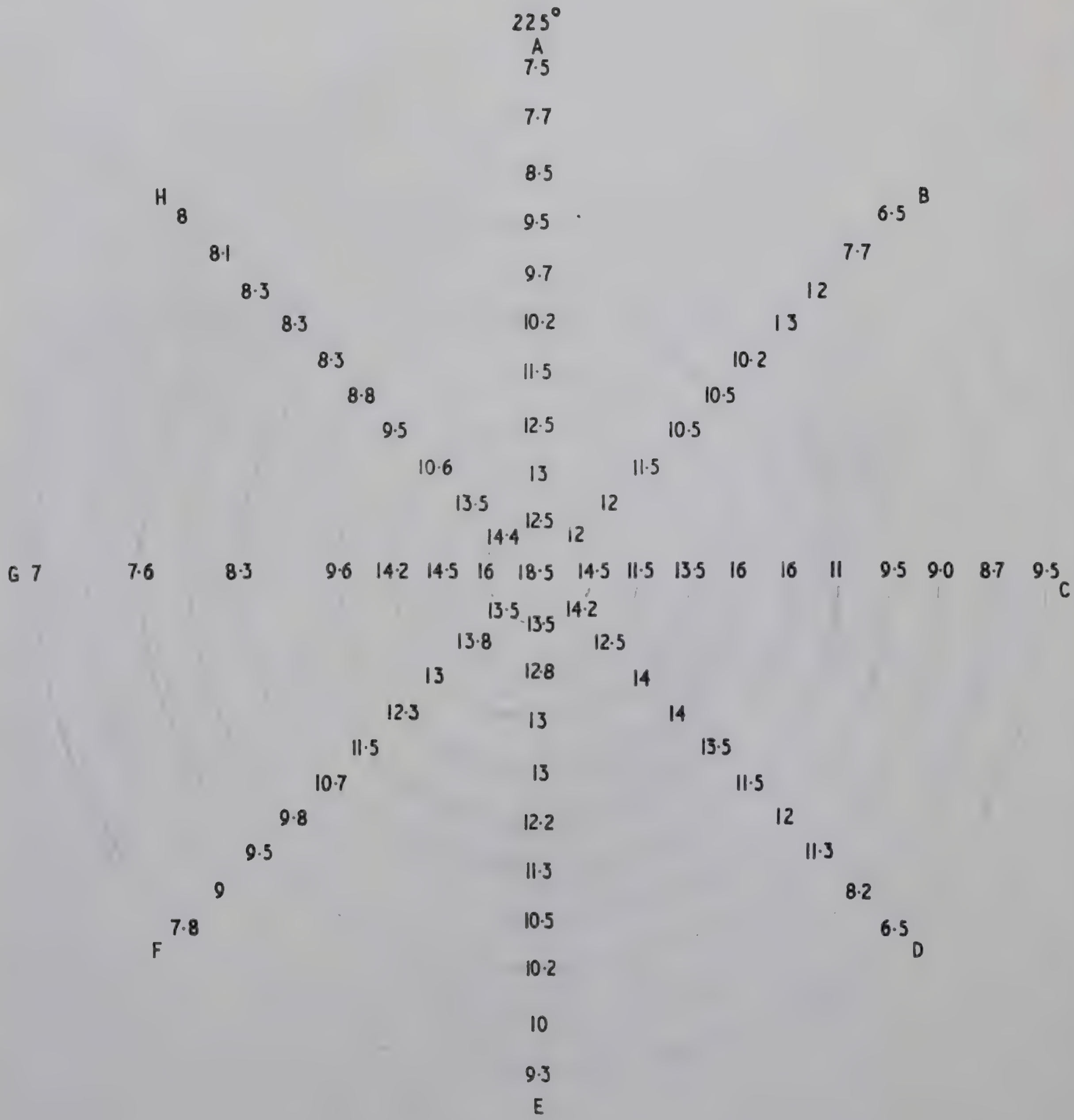
Using the measured decay factor up to 40 days, together with a theoretical decay to 630 days, which agreed with the Totem decay up to 40 days and with the Hurricane up to 400 days, the centre values at H + 1 hour and D + 630 days have been evaluated and are shown below:-

Crater	H + 1 Calculated	D + 9 Measured	D + 630 Calculated	D + 630 Measured
Totem 1	4400 r/hr	5.3 r/hr	11 mr/hr	18.5 mr/hr
Totem 2	7750 r/hr	9.3 r/hr	19 mr/hr	16.0 mr/hr

It will be seen that the overall decay is in good general agreement with theory, but it is interesting to note that whilst Totem 2 had a much higher activity originally it is now somewhat lower. Although Fe 59 is undoubtedly present in the crater area this reversal of dose-rates cannot be attributed solely to the addition of this isotope to the normal fission product distribution.

[redacted]

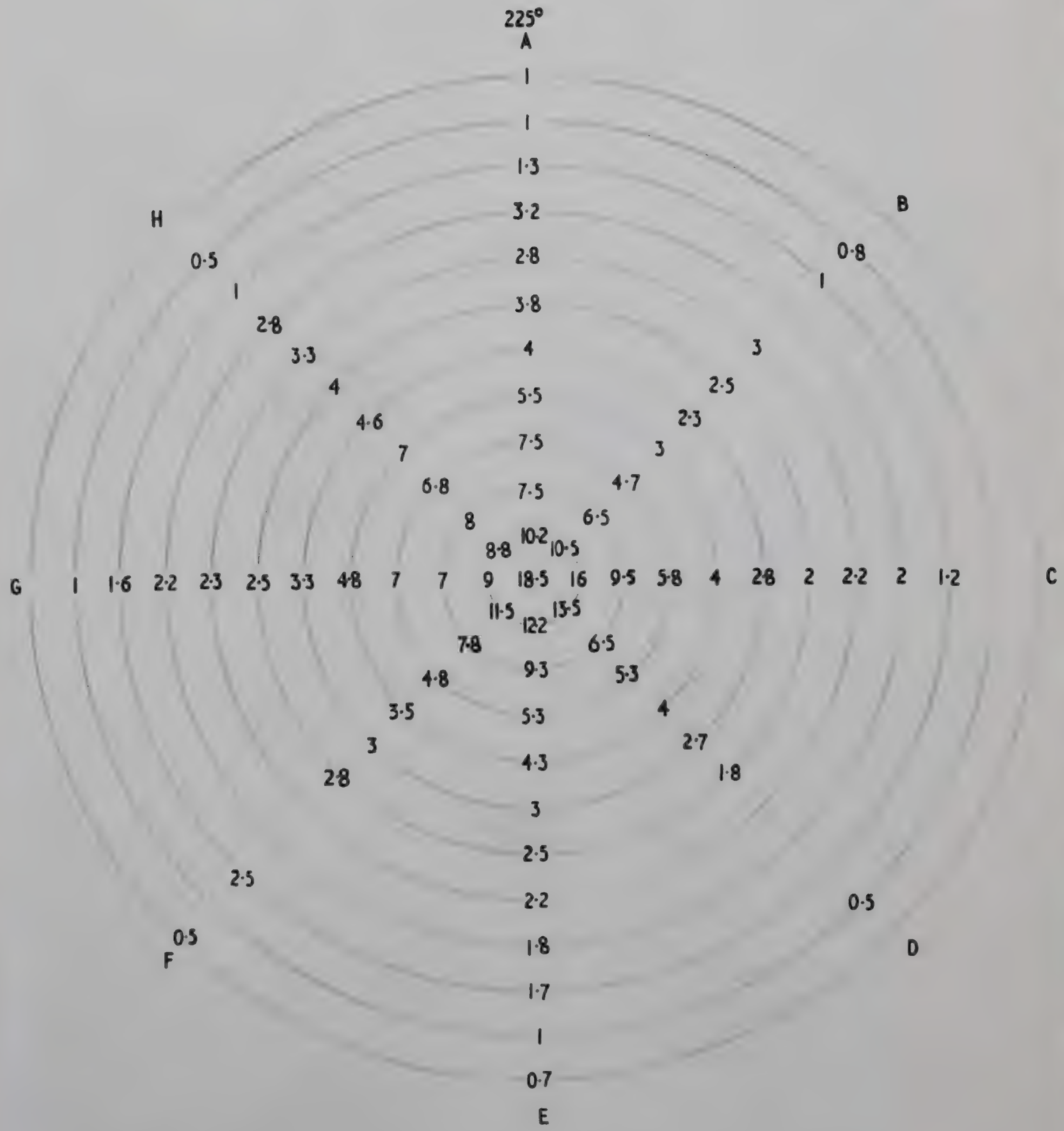
[redacted]



EACH CIRCLE REPRESENTS 5 PACES = 11 FEET.

FIG.6·1. DOSE RATE IN MILLIRONTGENS PER HOUR IN T.I. CRATER ON 5th JULY 1955.

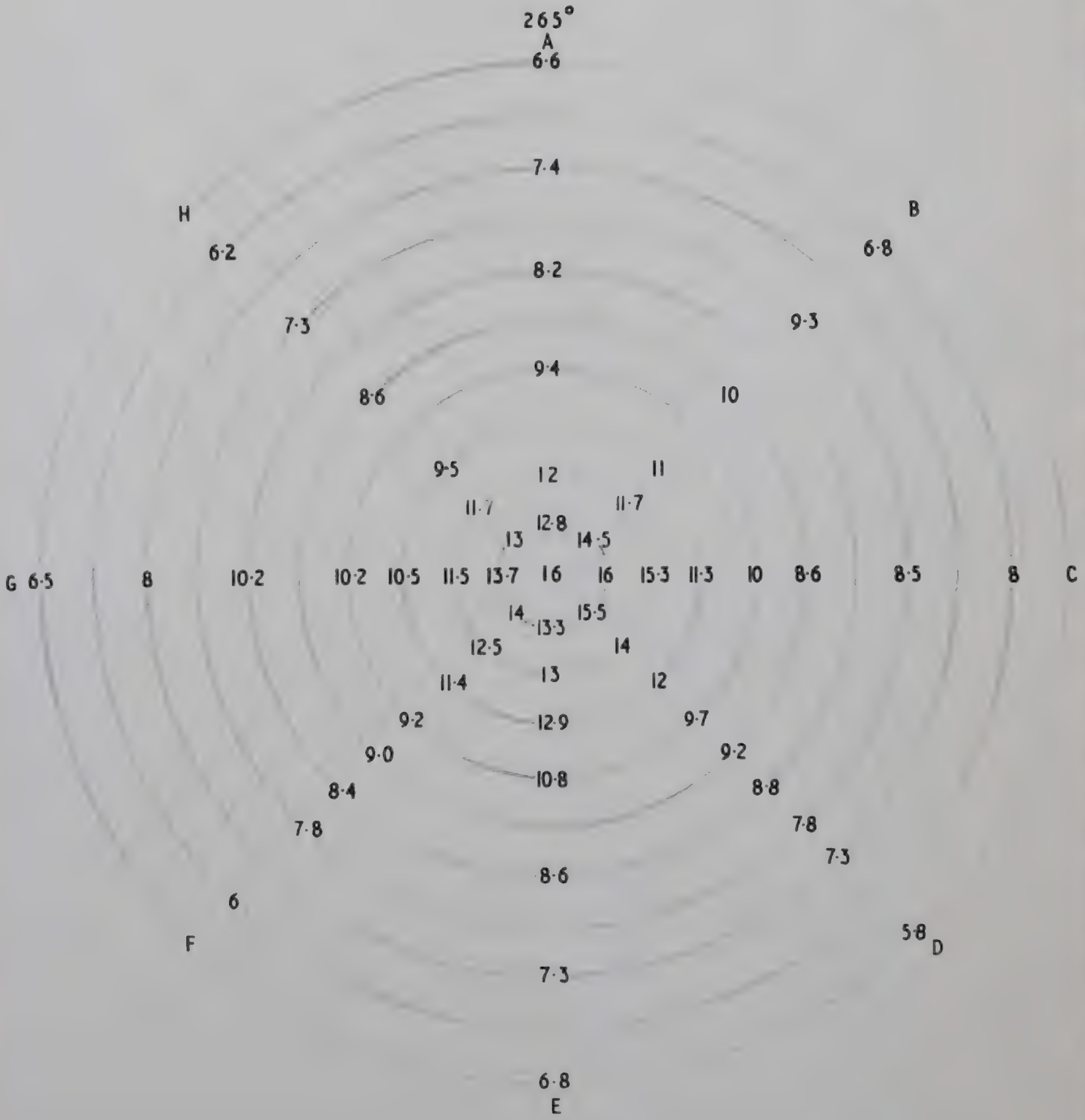
[redacted]



EACH CIRCLE REPRESENTS 25 PACES = 55 FEET

FIG 6·2 DOSE RATE IN MILLIRONTGENS PER HOUR IN T.I. CRATER ON 5th JULY 1955.

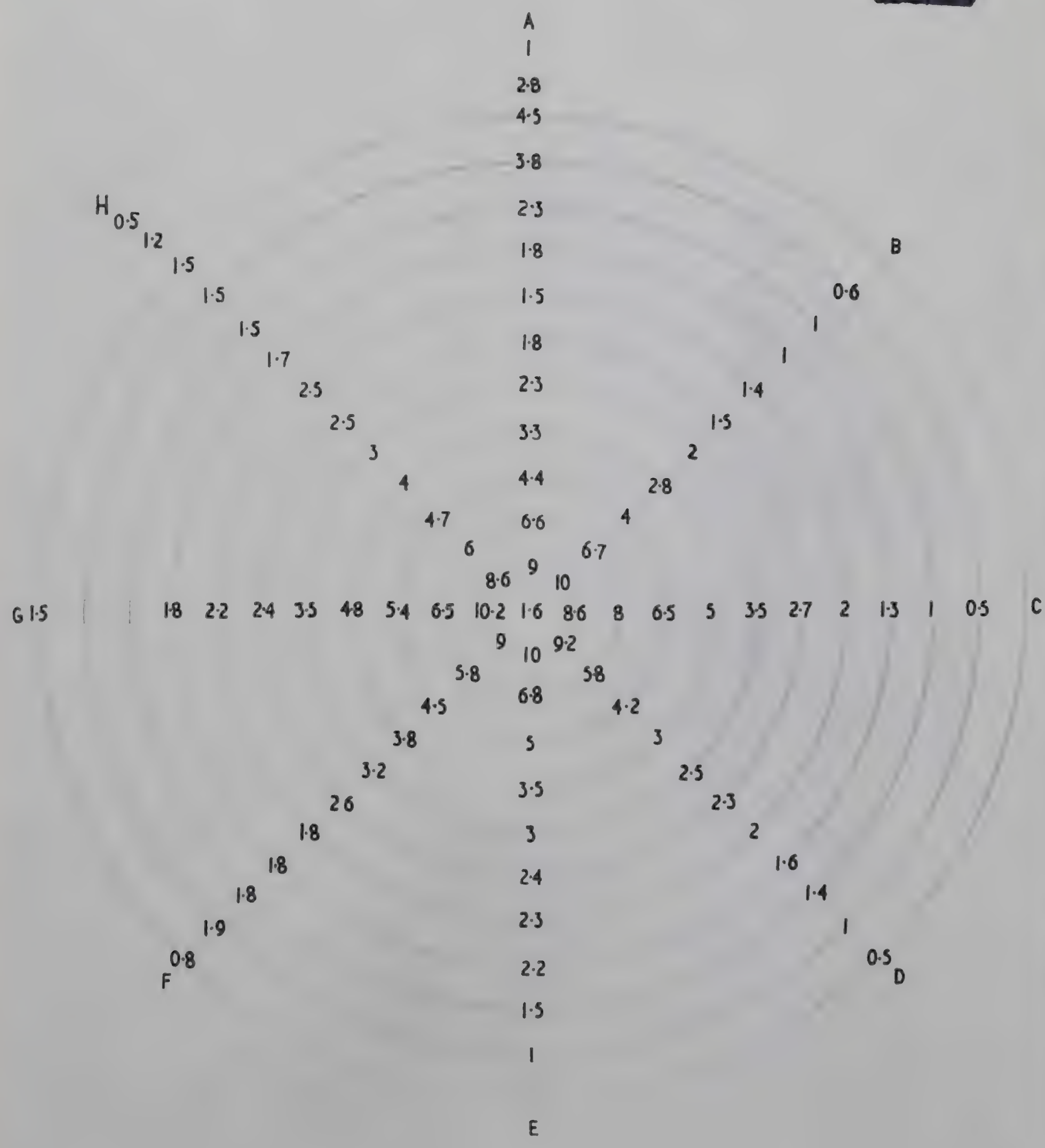
[redacted]



EACH CIRCLE REPRESENTS 5 PACES = 11 FEET.

FIG. 6·3. DOSE RATE IN MILLIRONTGENS PER HOUR IN T.2. CRATER ON 6th JULY 1955.

[redacted]



EACH CIRCLE REPRESENTS 25 PACES = 55 FEET

FIG. 6·4 DOSE RATE IN MILLIRONTGENS PER HOUR IN T. 2. CRATER ON 6th JULY 1955.

[redacted]

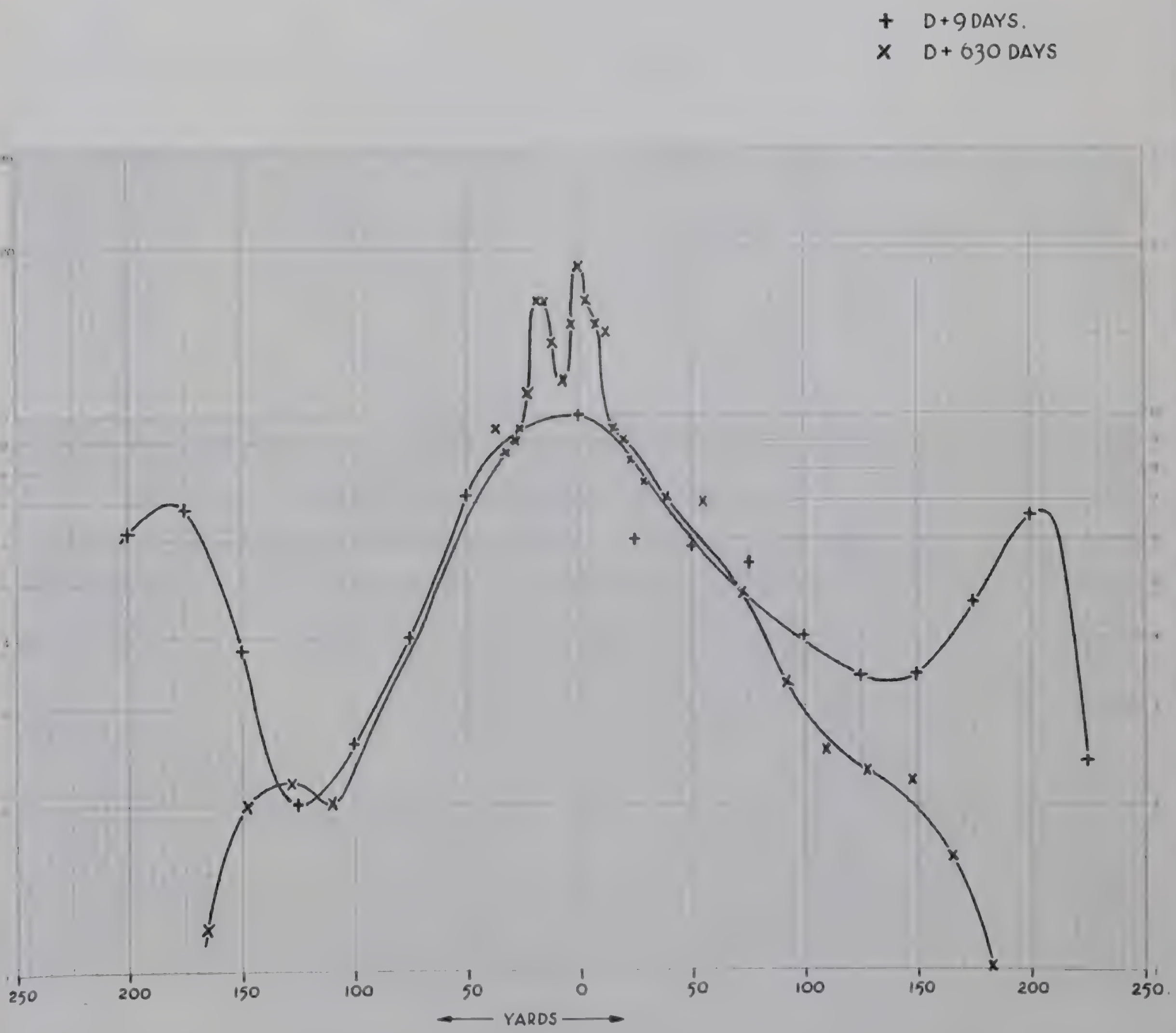


FIG. 9·1. TOTEM I CRATER SURVEY.

[redacted]

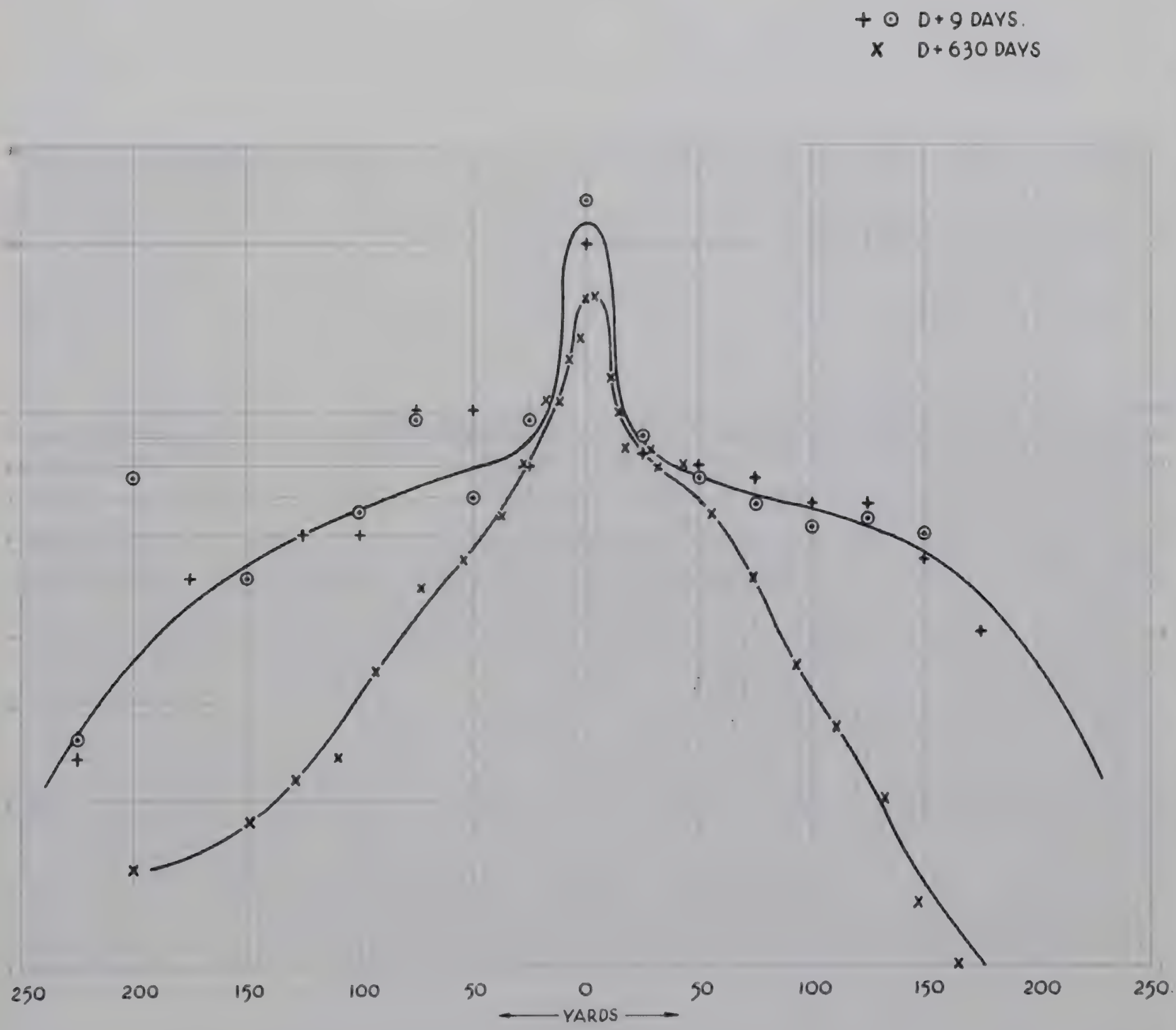


FIG. 9·2. TOTEM II CRATER SURVEY.

AWRE T 10/60

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ATOMIC WEAPONS RESEARCH ESTABLISHMENT

BB005

AWRE REPORT No. T 10/60

On the Resuspension in the Atmosphere of Radioactive or Other Fine Particulate Material Deposited on the Ground

K. Stewart

A.W.R.E.,
Aldermaston, Berks.

[redacted]

November, 1960

Report: AWRE-T-10/60
UK National Archives: ES 5/284

TABLE 1

Summary of Experimental Results on Resuspension of Activity $K\ (m^{-1}) = \frac{\text{Airborne Concentration (Curies } m^{-3})}{\text{Contamination Level (Curies } m^{-2})}$

Trial	General Circumstances of Measurement	Resuspension Factor: Range	Resuspension Factor: Mean
Hurricane 25 kt ship	Sample of airborne material obtained without artificial disturbance of ground surface (12 results)	1×10^{-6} to 8×10^{-6} but 10 values lie between values 0.47×10^{-6} to 1.6×10^{-6}	1×10^{-6}
Totem 8-10 kt bursts on 100 ft towers	Random samples collected in region of T1 crater in absence of artificial disturbance of the ground (9 results)	1×10^{-6} to 1×10^{-8}	2×10^{-7} (0.8×10^{-7} if one result at 1×10^{-6} excluded)
	Surveys on C and D roads of grid - no artificial disturbance of ground surface (14 results, with 6 indefinite but measured values all $< 2 \times 10^{-7}$)	1.5×10^{-6} to 1×10^{-8}	2.5×10^{-7} (or 0.8×10^{-7} if one result at 1.5×10^{-6} is excluded)
	Surveys on "Dingo" road - samples collected at back of Land-rover in motion (21 results, 10 of which 2 were obtained over the tailboard) on the 4th and 7th days after the first test	On 4th day: 0.8×10^{-6} to 3×10^{-6} On 7th day: 0.6×10^{-6} to 4×10^{-6} On 7th day: 1.6 and 3.1×10^{-6} at tailboard position	1.4×10^{-6} 1.5×10^{-6} 2×10^{-6} at tailboard
	Survey of road to Site C (10 results) on 1st and 2nd days after the second test. Of these, 3 are indeterminate but less than 2×10^{-8} and only 2 are $> 1 \times 10^{-6}$	1×10^{-8} to 2×10^{-6}	4×10^{-7}
Buffalo	Sample collected during an instrument recovery sortie in which the sampler, a cascade impactor, was carried in the driving compartment of a Landrover for part of the time and was outside the stationary vehicle near the working party for the remainder Round 1 (H + 18 hr) 15 kt on 100 ft tower Round 2 (H + 5 hr) 1.5 kt true surface burst	2.5×10^{-6} but only about 10% of the activity was present on particles < 6 μ diameter 6.4×10^{-6} but only about 20% of the activity was present on particles < 6 μ diameter	
Civil Defence Trial at Falfield	Representative brick/plaster dust sample contaminated with I-131 and distributed on greater amount of dust and used during two realistic Civil Defence, bomb-site, recovery trials. 1. Enclosed Space 2. Open Area	Dust loading: 110 mg/m^3 Dust loading: 10 mg/m^3	2×10^{-4} 2×10^{-6}
Some representative results obtained during Health Physics surveillance of minor experimental trials at Maralinga	1. Uranium (1957) sample collected immediately downwind of crater at: 1 ft above ground 2 ft above ground 1 ft above ground (dust stirred up)		3×10^{-4} 1×10^{-6} 1×10^{-8} Estimated that < 5% in hazardous size range
	2. Plutonium (1959 Vixen) sample collected at: 1 ft above ground: - dust created by vehicles - dust created by pedestrian	3×10^{-4}, 7×10^{-4} 1.5×10^{-6}, 3×10^{-6}	Particle size mainly 20 - 60 μ; estimated that < 1% in hazardous size range

Type of Particulate Material	Terminal or Deposition Velocity, m/sec	K, m^{-1}	Estimated Half-Life for Contaminated Zone (days) for: K 1×10^{-4}	K 1×10^{-5}	K 1×10^{-6}
Very fine dust) diameter ≤ 1 μ)	0.001 0.002	30 f 30 f	2.5 2.6	25 26	250 260
Fine dust up) to about 20 μ)	0.01 0.02	26 f 23 f	2.9 3.4	29 34	290 340
Coarse dust,) fine sand ~ 50μ)	0.1 0.2	10 f 5 f	16 160	160 1600	1600 16,000

TABLE 4

Theoretical Estimation of Airborne Concentration Downwind of a Heavily Contaminated Area

Contamination at Point P, μg/m²	Airborne Concentration, μg/m³	Dose Inhaled in 1 Day (f = 3×10^{-6})
500	65 f	4.7×10^{-3}
160	25 f	1.8×10^{-3}
13	1.9 f	2.1×10^{-4}

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ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 4/57

OPERATION BUFFALO

Target Response Tests

(Co-ordinator: E. R. Drake Seager)

The Decontamination of Radioactively Contaminated Drinking Water in the Field

Maj. D. B. B. Janisch, R. A.

et al.

[redacted]

UKR2.52

UK UNCLASSIFIED

A.W.R.E.,
Aldermaston, Berks

[redacted]

July, 1957

3.1 Production of Contaminated Water

An attempt was made to collect fall-out from Round 1 (tower burst) and the top layer of a few square yards of the soil in the fall-out area was collected so that there was sufficient activity present in the sample. On sorting this soil, almost all of the activity was found to be concentrated in a small number of tiny glass-like spheres obviously consisting of fused sand. These were of course found to be almost insoluble in water; facilities were not easily available, neither was it considered expedient, to conduct the rather elaborate chemical processes necessary to bring this material into a neutral aqueous solution. Because of this relative insolubility, drinking water taken from this area would probably have been acceptable from the radioactive point of view*.

In order to obtain samples of contaminated water, the filter papers from one of the cloud-sampling aircraft in Round 3 (air burst), were used. These were macerated, and the soluble portion of the fission products leached out. The samples were collected shortly after F hour; the leaching out took place during D + 3, i.e., about 70 hours after burst, and the water was treated on D + 4, i.e., 92 to 100 hours after burst.

* i.e., by the accepted military emergency standard, of being fit for drinking up to $2\frac{1}{2}$ litres/man/day for 10 days.

TABLE D1

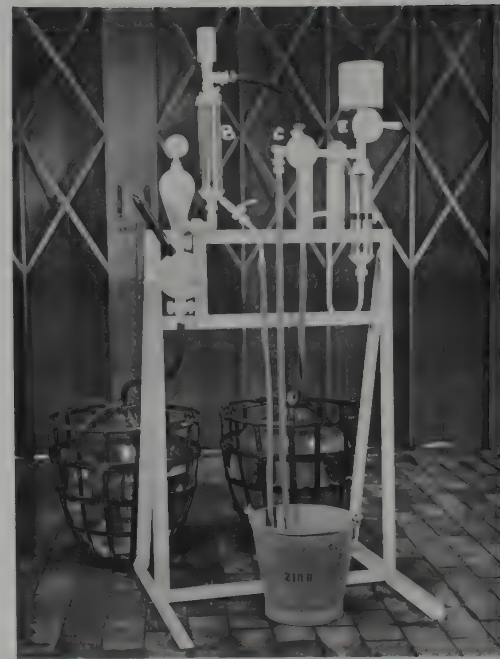
Sample	Hardness as $CaCO_3$, p.p.m.	μc per litre at D + 13			
		Gross β γ	^{131}I	^{89}Sr	^{140}Ba
Untreated (Sample C)	196	0.887	0.107	0.0177	0.052
3rd. gallon after one treatment (C_t)	1.9	0.087 (90%)	0.074 (31%)	0.00025 (99%)	0.0046 (91%)
3rd. gallon after two treatments (C_{tt})	2.5	0.030 (97%)	0.0217 (80%)	<0.00001 (> 99%)	0.000113 (99.8%)

NOTE: Percentages in brackets indicate percentage removal represented by the entry immediately above.

TABLE D2

Results of Laboratory-Scale Decontamination of Water

Sample	μc per litre at D + 7			
	Gross β γ	^{131}I	^{89}Sr	^{140}Ba
Influent Effluent	0.274 0.112	0.032 0.025	0.013 < 0.0012	0.0249 0.00025
Percentage removal	59	22	> 91	99



Filter and ion-exchange system

Key:
- A Pump
- B Metafilter candle and filter bed
- C By-pass cock
- D Brine tank
- E Cock
- F Ion-exchange bed

The carboy on the left of the photograph contains the raw water. That on the right receives the treated effluent. Waste, washings etc., are led into the bucket.

Figure 1.

NOTE: iodine-131 is difficult to decontaminate from water using earth filtering or even ion-exchange. Take KI tablets!

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Date .... 1957 ...... Initials ....

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Some recent information from the United States about fall-out from ground burst megaton weapons

1. Time of first arrival and duration

Data on these two aspects of fall-out have been given to us recently in two papers, one by Dr. Frank Shelton, Technical Director of the U.S. Armed Forces Special Weapons Projects entitled "Physical Aspects of Fall-out" and the other by E. A. Schuert of the U.S. Naval Radiological Defence Laboratory, in Report TR 139 - "A fall-out forecasting technique with results obtained at the Eniwetok Proving Ground".

On arrival times Dr. Shelton states "Fall-out from a detonation of the order of a megaton will begin to arrive on the ground over an area the order of the size of the visible cloud, almost like a blanket at about 15 to 20 minutes for a large yield surface burst on an island or presumably on land. Fall-out from a shot of the order of a megaton on a barge in water will begin to arrive at the surface at about 30-40 minutes".

[N.B. For the land or island shots the average particle size is greater than for water shots, and therefore the particles fall more quickly.]

"The above fall-out is exclusive of the vicinity of the crater and throw-out."

On fall-out duration, Dr. Shelton states "The radiation rate will build up on the ground under the cloud and reach a peak in about 100 minutes for a detonation of the order of a megaton".

With regard to any possible contamination hazard to people exposed in the open during this period, theoretical calculations and trials experience alike have shown that this is small compared with the hazard of the external gamma radiation from the surroundings and can in fact be made negligible provided that a few simple precautions (wearing of gloves, shaking or brushing down or removal of outer garments, and washing of the face) are taken at the first opportunity.

2. Upwind Contamination

The advice given by Scientific Advisers' Branch to the Working Party was based on information exchanged at a conference early in 1954 which gave a dose-rate of 10 r.p.h. at H + 1 at a distance 9 miles upwind of ground zero. A corresponding contour of 50 r.p.h. at H + 1 at 6 miles was quoted publicly by Govr. Val Peterson. Having in mind the date of the conference it is obvious that the only experience in the U.S. of megaton explosions at that time was of the one in November 1952.

Some time after the megaton explosion of March 1954 we were told that the U.S. were now convinced that contamination in the damaged area was heavier than this and it was for this reason that we suggested the inclusion of the "very heavy" contours in the chart which was circulated with the Working Party's Report and also suggested a modification of the script of the new H bomb film to indicate that the green line (3 r.p.h.) at H + 1 might be anywhere from 5 to 20 miles upwind of ground zero.

We are now confronted with the new U.S. book "The Effects of Nuclear Weapons", which seems to indicate that the contamination is greater still, an indication which must be examined in detail.

Using the data in Table 9.71 for a 1 MT explosion, and scaling up to a 10 MT explosion by means of the principles enumerated in paras. 9.74 to 9.77 we arrive at the rather startling result that the 10 r.p.h. contour at H + 1 extends 26 miles upwind (30 miles for the ground zero circle radius less 4 miles for the downwind displacement of the ground zero circle).

Note: Stanbury deduces from the Tewa test fallout data that ENW57 exaggerates upwind fallout!

WIND VECTORS FOR FALL-OUT PATTERN AT FIG. 1

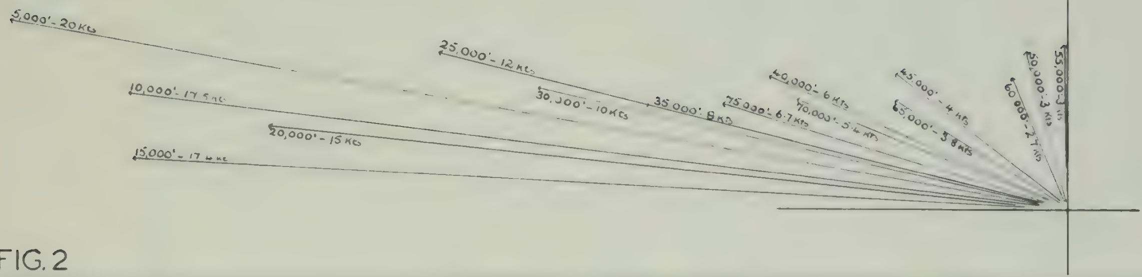
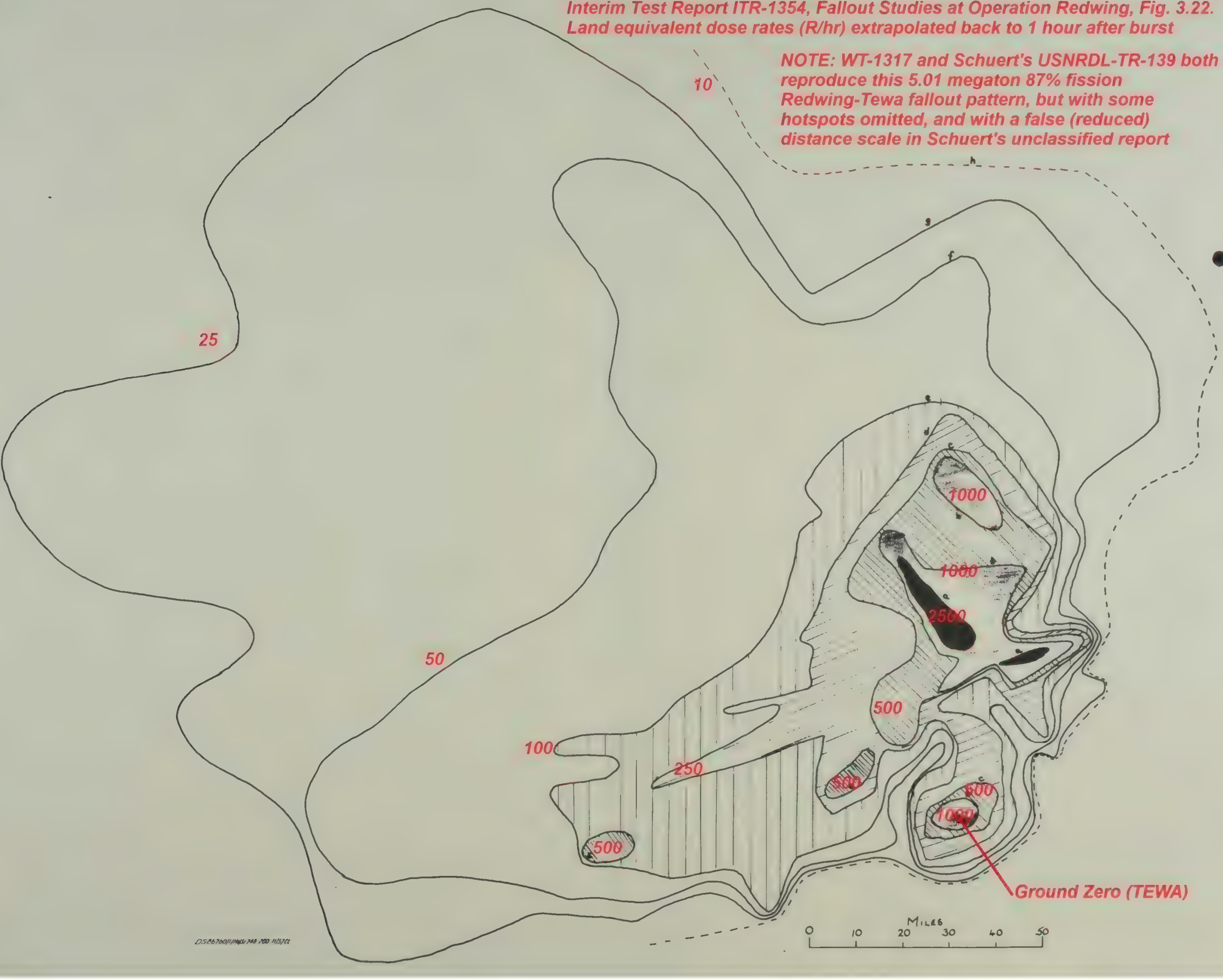


FIG. 2

TYPICAL FALL-OUT CONTOURS FROM A HIGH-YIELD GROUND-BURST EXPLOSION IN THE PACIFIC (LOW WIND CONDITIONS)

Interim Test Report ITR-1354, Fallout Studies at Operation Redwing, Fig. 3.22. Land equivalent dose rates (R/hr) extrapolated back to 1 hour after burst

NOTE: WT-1317 and Schuert's USNRDL-TR-139 both reproduce this 5.01 megaton 87% fission Redwing-Tewa fallout pattern, but with some hotspots omitted, and with a false (reduced) distance scale in Schuert's unclassified report



(As a result of changing USA supplied fallout data, the UK gave up analysing distances and just concentrated on the fallout areas contaminated under ~15mph wind speeds. This 1960 paper by Stanbury explains data sources!)

NOTE: these Confidential-classified reports by UK Home Office Scientific Adviser's Branch physicist George Reginald Stanbury, OBE (1903-73) refer to the 1957 edition of Glasstone's book Effects of Nuclear Weapons (based on nuclear test data for civil defence, not the false computer simulations later published).

Stanbury attended the 1952 Operation Hurricane UK nuclear test and analysed thermal and fallout data. This paper compares fallout areas in Glasstone and other sources like the Classified 1957 USA Capabilities of Atomic Weapons TM 23-200 and the 1959 UK Manual of C.D. v1 pamphlet 1, Nuclear Weapons booklet.

The latter shows that a 1 megaton fission surface burst gives 30 R/hr at 48 hours after burst over an area of ~50 square miles: this comes from Table 9.71 in Glasstone, 1957: the elliptical fallout belt for 15 mph wind is 22 miles long and 3.1 miles in maximum width, thus having an area of (Pi/4)(22)(3.1) = 52 square miles. For comparison, Fig. 4-14B in the Confidential American manual TM 23-200 Capabilities of Atomic Weapons, gives an area of just 28 square miles.

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Downwind fallout areas from ground-burst megaton explosions

1. Information available in 1958

(i) The U.S. publication "The Effects of Nuclear Weapons" paragraphs 9.71 to 9.73 *GLASSTONE, 1957 edition*

(ii) The U.S. publication "Capabilities of Atomic Weapons" fig. 4 -4B, prepared by the Armed Forces Special Weapons Project; originally highly classified but now downgraded to "Confidential". This is at present under revision. *TM 23-200*

A comparison of the various figures for a few dose rates is given in Table 1.

Table 1

Areas of downwind contamination (sq. miles)

NOTE: at 1 Mt, TM 23-200 Capabilities gives half Glasstone's E.N.W. fallout areas for 300-3000 R/hr at 1 hr

Dose rate contour @ H + 1 r.p.h.	1 MT; 100% fission		10 MT; 100% fission	
	(i) E.N.W. & U.K. Nuclear Weapons	(iii) Capabilities	(i) E.N.W. & U.K. Nuclear Weapons	(iii) Capabilities
3000	54	27	540	650
1000	210	110	2100	1750
300	650	350	6500	5000
100	1500	1100	15000	18500
30	3300	3500	33500	43000

Difference

N.B. The Capabilities data is approximately summarised in the expression

$$AR = \frac{10^5}{P^{-1.2}}$$

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Where A = area in sq. miles

R = dose rate contour in r.p.h.

P = power of weapon in MT

NOTE: for 20 kt fission yield, Capabilities TM 23-200 Fig. 4-14A gives 80% of the fallout areas in E.N.W. 1957 for 10-3000 R/hr at 1 hr

(b) The fallout pattern (Triffet's Tewa fallout pattern from WT-1317.)

This is Fig. 7 on page 80 of the 1959 Congressional Hearings and is stated to be for a 5 MT explosion. No fission yield is actually given although, as the whole of the article in which this pattern appears is concerned with a 50% fission yield weapon, it seems reasonable to assume that this pattern is also intended for a 50% fission yield. (Redwing-Tewa, 5 Mt, 87% fission)

The 25 r.p.h., 100 r.p.h. and 500 r.p.h. contours have been integrated and the areas compared with those from Capabilities in Table 3.

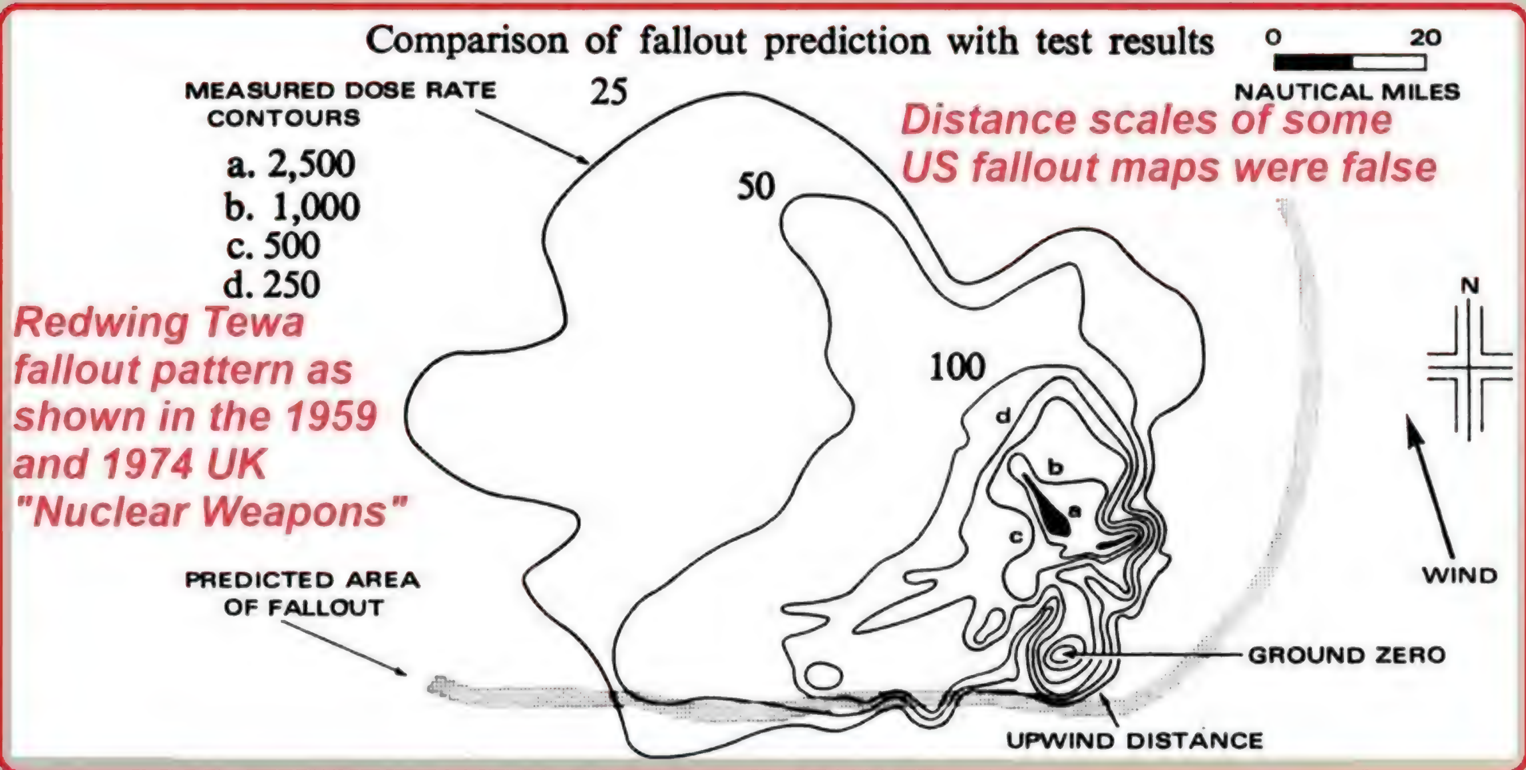
Table 3

Areas of downwind contamination (sq. miles)

Comparison of U.S. fallout pattern with Capabilities

Dose rate contour @ H + 1 r.p.h.	5 MT: 50% fission	
	Redwing-Tewa Fig. 7. p.80 1959 Hearings	Capabilities
500	2,000	750
100	6,000	3,300
25	30,000	12,000

NOTE: when the Capabilities data is corrected from 50% to the real Tewa fission yield of 87%, the REAL fallout areas are ~2 times Capabilities data, i.e. equal to the 1957 E.N.W. data!



G. R. STANBURY

November 1960.

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Casualty Estimates for ground burst 10 Megaton bombs

AUTHOR: EDWARD LEADER-WILLIAMS, 1 OCTOBER 1956

1956

Summary

Tentative estimates of casualties from up to 45 ground burst 10 megaton bombs on British cities are estimated for various conditions of shelter and evacuation.

Casualties from an attack aimed in the optimum way (to cause casualties) when there is no shelter or evacuation are found to range from over $2\frac{1}{2}$ million killed by a single bomb to just over half a million per bomb by 45 bombs. The total evacuation of the evacuation areas shown in Fig. 8 is found to reduce fatal casualties from this attack by from 99 to 84% depending on the number of bombs. Similarly the evacuation of the priority classes (45%) combined with the provision of a high standard of shelter for the remaining inhabitants of the evacuation areas would reduce fatal casualties from this attack by from 99 to 88% depending on the number of bombs. These are the maximum savings that could result from these policies. If the enemy adjusted his attack so that all his bombs were aimed at reception areas, thus achieving the maximum casualties among the evacuated and/or sheltered population, the reduction in fatal casualties would range from 62 to 44% for the policy of 100% evacuation, and from 79 to 65% for the policy of 45% evacuation combined with shelter. In the event of either of these policies being adopted the enemy would probably make some adjustments in his attack without going as far as in the limiting case above of aiming all his bombs at reception areas. The saving in casualties would then be intermediate between the two sets of figures given above.

3. The shape and size of the fall-out pattern. The size and shape of the fall-out pattern for a ground burst 10 megaton bomb has been determined from the data presented at the February 1954 Tripartite conference*. The pattern consists of an ellipse with one apex at ground zero together with a circle centred a short distance down wind of ground zero. This pattern is reproduced as Figure 1 and the principal dimensions of some of its contours are shown in Table 1.

* 15-19 Feb. 1954, "Tripartite Conference: Effects of Atomic Weapons on Human Beings and their Environment", Washington D.C., AFSWP & USAEC Secret

TABLE 1

Principal dimensions of fall-out pattern from ground-burst 10 megaton bomb with a 15 knot wind

(This secret Tripartite conference included Canada, USA and UK.)

Dose rate (r/hr at 1 hour)	Down wind length of ellipse (miles)	Cross wind width of ellipse (miles)	Radius of ground zero circle (miles)	Down wind displacement of ground zero circle (miles)
5000	23	5.5	2.6	1.5
3000	33	7	3.1	1.7
2000	45	8	3.6	1.9
1000	72	11	4.5	2.3
500	115	16	5.7	2.6
300	160	22	6.8	2.8

Note: these data are from 1951 Jangle-S (1.2 kt) for downwind areas and 1952 Ivy-M (10.4 Mt) for upwind and crosswind of ground zero, with both distances and dose rates scaled by the cube-root of total yield (USNRDL-TR-1). This was incorporated into the June 1957 Effects of Nuclear Weapons edited by Glasstone. 1956 Redwing data showed upwind dose rates had been exaggerated 10-fold.

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IDEALIZED LOCAL CONTOURS
FOR RESIDUAL RADIATION

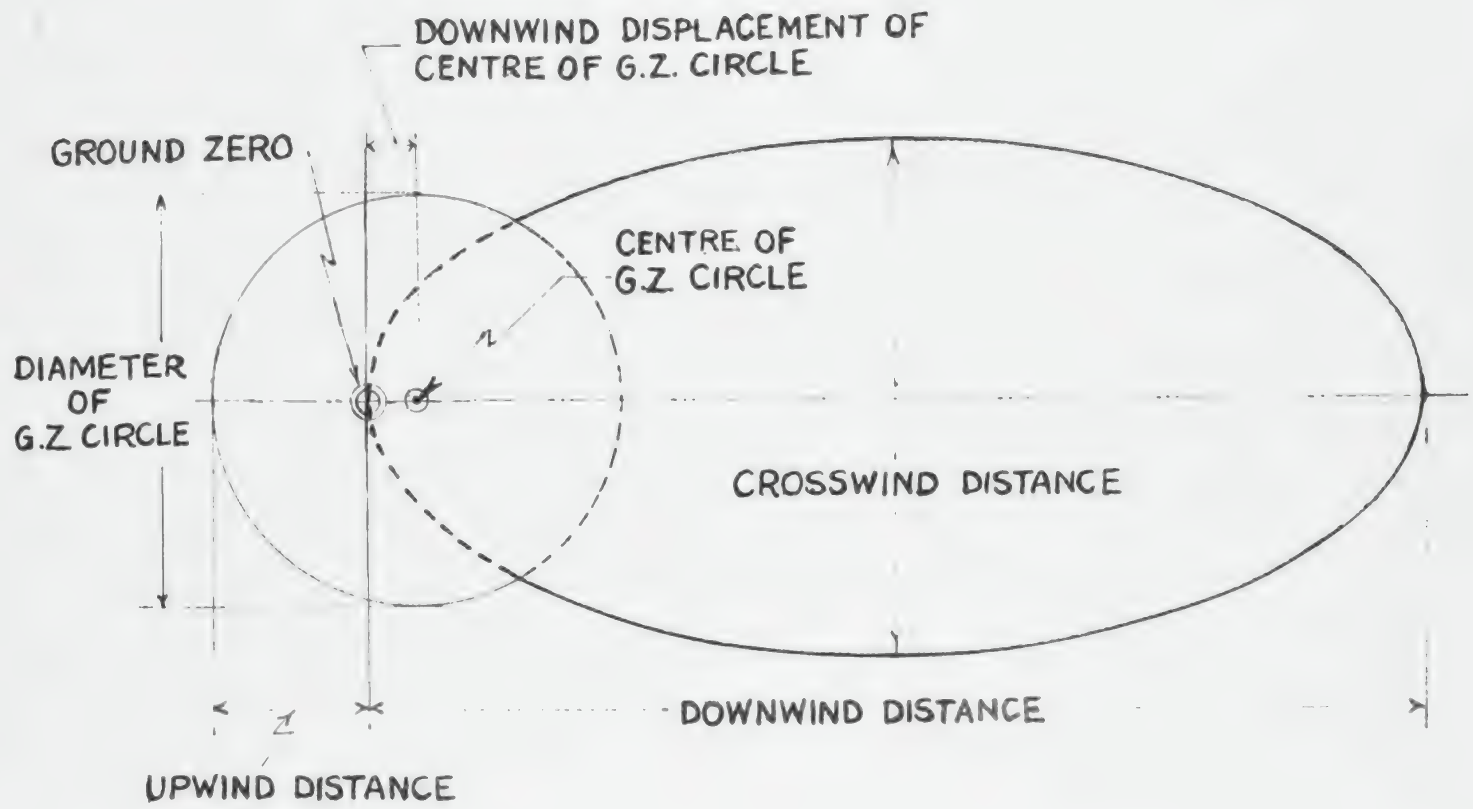

FIG. I

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22/5/90

Regional Scientific Adviser's Conference
15th-17th May 1962

The Soviet Strategic Air Threat to the United Kingdom

Mr. H. S. Young
(Deputy Director, Joint Intelligence Bureau)

Although the title of my Talk today is the strategic air threat to the United Kingdom, I thought it would be more useful to you, as Scientific Advisers to the Home Office, to talk about the strategic air threat to the West as a whole. The threat to the United Kingdom is all too easy to understand. It is, however, the threat to the West, as a whole, which determines the likelihood of war.

The Russian development of weapons since World War II falls into three natural periods. It must be remembered that, in general, Russia fought only land battles in World War II. She did not fight an air war or a scientific war, and therefore she found herself at a grievious disadvantage at the end. For the first five years of the post-war period she devoted herself to copying Western equipments, particularly those for air defence, i.e. radars and fighter aircraft. She also began building a large submarine force, but as these submarines were all of short endurance, this arm was clearly intended to play a defensive role against aircraft carriers rather than to attack our lines of sea communication. The whole accent during this period was on defence, and the only offensive items tackled in this period were the copying of the American B.29 Super Fortress, which became the Russian Medium Bomber TU4, and the outstandingly high class nuclear weapon programme which resulted in the first Soviet nuclear explosion in the second half of 1949.

The next five years may be classified as the "belt and braces" period. Russia continued to produce new marks of orthodox equipment whilst initiating research programmes on novel weapons. During this period she began research and development on guided weapons of all types, and began her work on nuclear submarines. Great emphasis was put on surface-to-air guided weapons, and this again emphasises her defensive outlook. Her first heavy bombers - the Bear and the Bison - appeared during this period. This was the first indication of a strategic offensive capability.

During the next six years she has been phasing out the older weapons in favour of new ones. The first ICBM was fired in the middle of 1957, and the first space vehicle was launched two months afterwards. Obviously, the Russians were very impressed by the political impact of the first sputnik and they subordinated the I.C.B.M. programme to that of sputniks and lunar probes for the next year. In the meantime, the production of heavy bombers continued at a very slow pace, and this, combined with the easy progress of the I.C.B.M., indicated that the Russians were in no hurry to develop a strategic offensive capability. Another most interesting development during this phase has been the missile submarine programme, and the Russians are devoting very great efforts to this weapon system.

The present Soviet air order of battle amounts to about 200 heavy bombers and about 2,000 light medium bombers. Taking the likely attrition rate into account, the threat that this presents to America is very small whilst the threat presented to the United Kingdom and NATO installations in Europe is exceedingly great. It is interesting to note that the number of Soviet day and all-weather fighters is about 8,000 which again emphasises her defensive outlook.

The missile threat has much the same character. The number of I.C.B.M. launchers available is probably less than 20, and there is no certainty that the Russians have any operational missiles at all. The number of intermediate range

and medium range ballistic missile launchers probably amounts to about 300. Again, this poses a minor threat to the United States and a major threat to the United Kingdom and the NATO installations in Europe.

Bearing in mind that both sides almost certainly have an adequacy of fissile material, what does this all add up to? It probably means that the United States has a nuclear advantage of about 5 to 1. The quality of her deterrent is much higher, and there is much greater diversity. In terms of operations, it means that a Soviet first strike does not make sense, but an American first strike does. It means that Soviet strategy is:-

(a) Deterrence of the United States against cities, and

(b) Deterrence of Europe against everything.

On the assumption that the Soviets intend to continue their programme of I.C.B.M. production, they will certainly be able to have several hundreds of them in, say, five years. But it is far from certain that she intends to do this and, in view of the efforts which she is putting into her missile submarine programme, it may well be that, as with the heavy bombers, the number of land-based I.C.B.M.'s may remain small, and her major strategic missile threat may come from the se

During the discussion which followed, Mr. Leader-Williams said that the figures given by Mr. Young for the USSR Order of Battle did not agree with the data produced for the US Congressional Hearings. Mr. Young stated that the figures he had presented were almost certainly more recent than those quoted at the Congressional Hearings. The US now agreed with JIB's assessment. Sir Charles Ellis asked how US and USSR I.C.B.M's compared with regard to accuracy at comparable ranges. Mr. Young said that they had insufficient data on USSR weapons to make a valid comparison. Whilst the fall of missiles had been observed, one could not be sure of the aiming point. From the small amount of evidence available it appeared that the C.E.P. at operational ranges is of the order of 1 to $1\frac{1}{2}$ miles. Mr. Western asked where the 57 MT weapon fitted into the picture. Mr. Young said that we were not at all clear about this. It was delivered by the Bear and it was possible that the Russians had not yet developed a missile large enough to deliver it. It could possibly have been developed for Mr. Kruschev's Global Rocket. Its use in an anti-missile missile appears unlikely. Mr. Western asked if the Russians could deliver it to targets in the U.S.A. Mr. Young said that this was not possible with the Bear unless it could be refuelled several times en route. Mr. Garrard asked whether in view of their age we ought to disregard the TU-4's. Mr. Young replied that the TU-4 is probably obsolete and is being replaced by Beagle. Dr. Ollis asked how the attrition rates vary with the different methods of delivery. Mr. Young said that the US Air Defence would take a heavy toll of the Bear and Bison. The picture might change when the supersonic bomber came into service. The attrition rate by the UK Air Defence might well be lower. With regard to the ICBM, the USSR has a huge programme of Anti-ballistic Missile defence, but there are as yet no signs that missile sites have been constructed. The US is developing Nike-Zeus, but whether this will ever get into service is another matter. Its cost will be astronomical even by today's standards. In UK we consider the decoy problem to be insoluble. Now that the weight of megaton warheads can be much reduced, there is room in the missile for more decoy equipment. Warheads can be destroyed if the defence knows the design. Conversely, if the defence is known a warhead could be designed to outwit it. The problem is thus very complex and a successful solution is likely to prove very expensive.

CD.14736.

SA/PR 74

Review by Dr John McAulay, UK Home Office Scientific Advisory Branch, 1963

"Fall-out and Radiological Countermeasures Vol I"

Prepared by Carl F. Miller

for OCD, Washington and issued January 1963

Miller's simplified model based on Anderson's dynamic cloud model

The outstanding value of this report lies in the method used by Miller to adapt a mathematical model for reproducing the geometry of the fireball (pp. 141, 142 & 147) and of the rising cloud and stem (pp. 207-209) and pp. 211-214). This model was originally proposed by A.D. Anderson in USNRDL Report 249 dated 1958. In this model the hemispherical fireball of a groundburst becomes a sphere as it leaves ground level; it then expands adiabatically as it rises to culminate in a stable oblate spheroidal cloud after the toroidal motion has ceased. The stem is the volume swept out by the rising, expanding fireball and fall-out of the larger particles starts as the fireball rises. Of the particles carried to the top by toroidal motion, the heavier ones are thrown at high speed downwards from the periphery of the cloud (p.217), contributing to the high intensity peak from the stem near ground zero and usually separated by a skip distance from the ridge of high intensity caused by particles that fall from the stabilised cloud.

Miller uses the Anderson cloud model, in modified form, to describe the descent of fall-out particles and to calculate for any selected location, The particle size, the mass deposit per unit area and the associated activity of the particles, from specific nuclear detonations of known depth or height of burst, of known fission and total yield and of known type of fissile material (see fission type relationship in Fig. 5.5 p.185).

The name "simplified model" may be appropriate in principle but it is questionable in practice. Nevertheless, as Miller claims, his simplified model does appear to offer a better reproduction of fall-out patterns from nuclear weapon trials than any of the other models devised to-date (see comparison of model predictions pp. 293-298).

The modification of the Anderson model consists in the separate treatment of the fall-out from the stem and from the cloud and in the use of a schematic intensity profile along the central "hot" lines of an idealised fall-out pattern. Fig. 5.1 p.233 illustrates the double humps of high intensity and the selected nine radiation intensity reference points along the "hot" line from the upwind edge to the downwind limit. Point 8 corresponds to the maximum pattern half width. Miller also introduces a particle size-location parameter α (see p.207-208 defined as

$$\frac{\text{wind vector}}{\text{particle fall velocity}} = \frac{\text{downwind distance}}{\text{height from which particles fall}}$$

From fall-out patterns at weapon trials, a number of relationships are derived, based on the assumptions listed on pp. 211-212 connecting the various parameters from one reference point to another along the central hot line. Thus relationships are established -

(i) between the parameters α and fission yield W (p.249-250)

(ii) between upwind and downwind distances X and fission yield, sometimes through other parameters which can be related exclusively to fission yield, such as Rs the radius of the fireball as it leaves the ground and stem variables for height Z and radius a with suffixes relating to position (p.250).

(iii) between radiation intensity* and W, X or α (p.251-252)

(iv) between yield and half width Y_s of the stem pattern bulge

(v) between yield and maximum half width Y_8 of the cloud pattern ellipse (pp. 245-251).

These empirical relationships are summarised in Table 5.3 p.254 for 100% fission yields of 1 KT to 100 MT and a single direction wind speed of

15 mph. The construction of an idealised fall-out pattern for a 1 MT fission yield in a 15 mph wind is illustrated on pp. 255-258 and Fig. 5.2 p.257 shows radiation intensity vs distance plots with distance from point to point.

The effect of different wind speeds is dealt with in pp. 244-245 and consideration is given to the possible crosswind shear effect on pp. 288-293 and Table 5.11 showing the ratio of lateral expansion to downwind travel of the bulge in the cloud pattern for different values of cross windshear Sy in knots/1000 ft. and for fission yields from 1 KT to 100 MT.

The build up of fall-out (TOA to TOC) at 1.87×10^{5} ft. (ca. 35 miles) downwind on the central hot line from a 1 MT fission groundburst in a wind speed of 15 mph is tabulated as a function of the particle size - location parameter α on p.261, Table 5.5.

<u>Relation between radiation intensity and mass deposit per unit area in Miller's model</u>

There still remains the problem of relating radiation intensity at any point in a fall-out pattern to the mass deposit of fall-out per unit area at that point. For this purpose Miller introduces the term <u>Mass Contour Ratio</u> at any time t, with the symbol $M_r(t)$, defined on p.301 as the ratio of the mass of fall-out per unit area to the dose-rate at the 3 ft. level measured at H + t hours. The values of $M_r(t)$ and hence of $M_r(1)$ at H + 1 hour are obtained from measurements at weapon trials in units such as mg/sq. ft. per rph at 1 hour.

It has been found that the inverse of the activity in mg/KT (or mg/fission) for equal values of α tends to decrease slightly with yield by a factor $W^{-0.083}$ and Miller accounts for this (p.304 & 321) by introducing a function $f(\alpha)$ in mg/KT or mg/fission where $f(\alpha)$ is proportional to (the dose rate at 1 hour.$M_r(1)$. $W^{0.083}$). This in turn leads to the general expression (6.16 p.325).

$$M_r(1) = \frac{f(\alpha) . W^{-0.083}}{D . q_x . B \left[r_\alpha(1) . i_{fp}(1) + i_i(1) \right]}$$

where W is the total yield in KT, B is ratio of fission to total yield, q_x is a ground roughness factor and D is the instrument response factor, so that the quantities within the square brackets are absolute air ionisation rates at H + 1 hours, 3 ft. above an ideal plane uniformly contaminated with actual (fractionated) fission products corresponding to a surface contamination density of one fission per sq. foot. The term $i_{fp}(1)$ is the true contribution which would have been made if all the fission products had reached the ground without fractionation and $i_i(1)$ is the contribution from the induced activity. The term $r_\alpha(1)$ is the fraction of the total fission products per fission actually reaching the ground at locations having the particle size location parameter α. Putting in values of 0.75 for D, 0.75 for q_x, 6.9×10^{-13} and 0.13×10^{-13} (rph at 1 hour/fission/sq. [illegible] respectively for $i_{fp}(1)$ and for $i_i(1)$ from p.231, gives equation 6.17 on p.325.

$$M_r(1) = \frac{1.83 \cdot 10^{11} f(\alpha) \cdot W^{-0.083}}{B \left[r_\alpha(1) + 0.019 \right]} \qquad \frac{\text{mg/sq. ft.}}{\text{rph at 1 hr.}}$$

Values of α are determined from the mathematical model and from weapon trials data, Miller has plotted $r_\alpha(1)$ vs α in F6.2 p.320 and $f(\alpha)$ vs α in Fig. 6.3 p.324. The latter curve can be treated as three straight sections from which three empirical equations are derived on p.325 relating $f(\alpha)$ to α for values of α from 0.1 to 0.9; from 0.9 to 20 and for $\alpha > 20$: this last equation is guesswork as no experimental data are available for $\alpha > 20$.

Hence for any selected point for which α can be determined the dose-rate at 1 hour and the mass of fall-out deposited per unit area can be calculated.

a function of

Since a fall-out producing detonation may occur below or above ground level, Miller introduces (p.327) a mass correction factor K_λ related to λ, the cube root of the yield and the height or depth of burst. Fig. 6.4 p.328 shows K_λ plotted against from weapon trials and that it is in good agreement with values calculated from the crater volume.

Miller also deals in detail with fall-out from sea water for which fractionation is less (i.e. fractionation factors are larger (see Fig. 6.2 p.320 and pp 327-337).

Thermadynamic processes in the Fireball : Fractionation of Fission Products and Induced Activity

A. General Comments

These aspects of nuclear detonations are discussed by Miller in Chapter 3 which is the most speculative and least successful part of the report relating to the development of a mathematical fireball and cloud model. Some general comments may not be out of place, therefore, before the problems of incorporating fractionation and induced activity into the mathematical model are considered.

The lack of adequate experimental data in these fields force Miller to exemplify his main arguments by a number of arbitrary assumptions (pp. 133, 152, 154 and 157). The two most important are (i) that the soil lifted into the fireball has an "ideal" composition $Na_2O \cdot Al_2O_3 \cdot 6\,SiO_2$ with a melting point of 1400°C and other corresponding properties (p.133) and (ii) that "half an energy in the fireball, at the second maximum, is used to heat dissociate and expand the gas molecules from the air and half is used to vaporize, dissociate and expand the gaseous products from the soil" (p.133). This "ideal" soil corresponds to a desert sand so that comparison is possible between calculations, based on Miller's model and those based on weapon trials in Nevada, for the fraction of the energy required to vaporise and melt the soil in the fireball. Miller estimates (p.151) that over the range 1 KT to 100 MT for groundbursts this amounts to between 7.5 and 9.2% compared with an estimate made by C. E. Adams of USNRDL, of about 3% for tower shots and since a larger fraction of the energy would be used in groundbursts than in tower bursts, the agreement is quite good. Of the crater mass lifted ~~into the fireball~~, Miller estimates (p.154) that the fraction of this soil melted varies from 3.8% to 12% for detonations of 1 KT to 100 MT.

The comparison is more difficult for detonations on coral (p.156-157) where the carrier soil particles consist of CaO with a high melting point of 2580°C and the particles can react with moisture and carbon dioxide in the atmosphere before being deposited on the ground. Nevertheless Miller claims (p.157) that his model gives values for the amount of liquified carrier soil per unit volume of fireball at the soil melting point temperature, $[n(l)/V]$ agree with observed data within a factor of 2.

Miller admits on p.146 that the absolute values of the data in many of his Tables and used to calculate the fractionation factors of individual isotopes in fission products are of questionable use for C.D. planning purposes. Nevertheless the general trends and relative values, deduced from his model, for the fission products that could be deposited in fall-out from a nuclear groundburst give a highly informative picture of the processes that cause fractionation and give also valuable approximations of use in C.D. planning.

B. Two stage condensation process in the fireball.

Chapter 3 considers all the thermodynamic processes which occur in the fireball such as, (a) the vaporization, dissociation, recombination, condensation and solidification of the soil material lifted from the crater (eqn. 3.166 p.154), (b) the successive condensation of fission product isotopes or their oxides etc. as the fireball colls to their respective melting points and (c) the large fraction of the fireball energy used in heating and dissociating the oxygen and nitrogen (mainly the former, pp. 122-123) occluded in the rising and expanding fireball.

The fission product condensation process is dealt with in two stages, when the fireball temperature is above and when it is below the melting point of the carrier soil. In the first stage the more refractory, higher boiling, oxides of the fission product isotopes condense onto the droplets of liquid soil and diffuse into the interior of each droplet. In this form they are not biologically available for uptake by and incorporation into plants and animals, when the solidified particles reach the ground. During the second stage, as the fireball cools through their successive boiling points, the other fission product isotopes or their compounds condense on to the surfaces of the solidified carrier soil particles. Since larger particles fall earlier out of the rising fireball, those fission products of lower boiling points condense later on to smaller particles which are carried further downwind with increasing biological availability to plants and animals (p.77 shows solubility - particle size relationships for underground, tower and balloon bursts at Nevada). Those fission product isotopes which are permanent gases or have gaseous precursors tend to escape from the fireball and cloud.

C. Fractionation of fission products

The general effect of the condensation process can be seen in Fig. 6.2 p.320 based on weapon trials (p321), in which $r_\alpha(1)$ is plotted against the particle size-location parameter α which increases with downwind distance: $r_\alpha(1)$ is the ratio of the H + 1 hour radiation intensity at the 3 ft. level, over (actual) fractionated to unfractionated fission products per fission per sq. foot at the location corresponding to the value of α. Fig. 6.2 shows that even at great distances from the point of burst i.e. for $\alpha > 100$, there will always be missing about 20% of the products ~~from each~~ per fission, escaping as gases from the fireball and cloud.

In Miller's model, the melting point of the soil material is arbitrarily chosen as 1400°C. The time for the fireball to cool to the

but escape in very small particles as world-wide fall-out beyond some arbitrarily selected contour usually taken as 1 rph at 1 hr. Miller quotes on p.296 (and some data in pp. 247 and 254 are also relevant) normalised data in rph at 1 hour per KT per sq. mile calculated from various cloud models devised to reproduce actual fall-out patterns in agreement with those at weapon trials. The data on p.296 are for 10 MT, 100% fissions and they are expressed as K(1)(C1) or K(1), where C(1) is the fraction of the fissions accounted within a dose-rate contour of 1 rph at 1 hr. For a real fall-out pattern therefore Miller gives

1460	rph	at 1	hr/KT/sq.	mile	from the ENW model
1500	"	"	"	"	from the WSEG-RM10 model
1500	"	"	"	"	from Anderson's model
1430	"	"	"	"	from Miller's simplified model

The above values represent 40-43% of theoretical air ionisation rates for unfractioned fission products (3610 from U238 by 8 Mev fission or 3940 for U235 fission see p.187). On the same page (296) Miller quotes corresponding values for K(1) which would appear to take into account the fraction of world-wide fall-out containing condensed fission products that would reach the ground (but presumably still excluding those which escape as premanent gases). These values of K(1) for the different models are:-

	2500 for the WSEG - RM10 model
	2400 for the WSEG - NAS model
Ca	2000 for the Weather Bureau model
Ca	2550 for the Miller simplified model

F. Home Office (SAB) comparison of Miller's normalised dose-rate and those given in the 1962 edition of the Effects of Nuclear Weapons (p.492)

It is interesting for C.D. planning purposes to compare the normalised dose-rate data quoted by Miller for different cloud models and the data in Fig. 9.179 (p.492) of the latest edition of ENW. The latter shows dose-rates, at 3 ft. above an ideal plane having a contamination density of 1 gamma megacurie per sq. mile, of 6.4 rph from 0.9 Mev photons (and 5.2 for 0.7 Mev photons) corresponding to 16.6 rph per gamma curie per sq. metre.

Since we are primarily interested in U-238 fission by 8 Mev neutrons at H + 1 hours we can use the basic data of Bolles, Ballou and Glendenin, quoted by Miller on p.180, and the photon energy for U-238 in Fig. 13.8 p.189 of just over 0.9 Mev from H + 1 to H + 2 hours (dropping regularly thereafter to 0.7 Mev at H + 8 hours). Interpolation gives 1.41 photons per sec. per 10^4 fissions at H + 1 hours and since there are 1.45×10^{23} fissions/KT (Miller's p.187) we get 2.04×10^{19} photons/sec/KT at H + 1 hours. Hence a contamination density of 1 KT per sq. mile at H + 1 hours corresponds $\frac{2.04 \times 10^{19}}{3.7 \times 10^{10}} = 550$ gamma megacuries

The ENW value of 6.4 rph per gamma megacurie/sq. mile corresponds therefore to dose-rates of 6.4 x 550 = 3520 rph at 1 hr per KT per sq. mile for U238 fission by 8 Mev neutrons and average photon energy of about 0.9 Mev. This is virtually the same as the normalised air ionisation rate of 3610 derived by Miller in Table 3.18 p.187.

It seems therefore that the data in ENW (1962) p.492 relate to absolute air ionisation rates in the sense used by Miller which thus require modification by factors for portable instrument and ground roughness shielding as well as fractionation factors of < 0.8 for fission yields under 1 MT.

For practical purposes therefore the value of 7.5 rph per (disintegration) curie per sq. metre usually accepted for CD purposes in the Scientific Adviser's Branch, Home Office, seems more than adequate for MT groundbursts on ground with a combined roughness factor and instrument factor of 0.5.

15 SEP 1963

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CD/SA 96

Reviewed April 1958

Declassified J.C.

Home Office
Scientific Advisers' Branch

The Decontamination of Residential Areas

Dr. J. McAulay

Effect of Type of Fall-Out

24. The type of fall-out will affect the effort needed to decontaminate access routes in a residential area. The fall-out may be typical of:

(a) a landburst in which the radioactivity is firmly fixed in the fall-out particles and there is no significant transfer of activity to the surface on which the fall-out is deposited even if the deposit is wetted by rainfall or is hosed or flushed away from the surface.

(b) an offshore and relatively deepwater burst in which large quantities of water and mud are lifted into the cloud so that the fall-out consists primarily of water droplets containing the radioactive fission products (or induced activity) in solution in colloidal suspension which can be transferred to the surface and be retained so tenaciously that the cost and effort of decontamination may be prohibitive.

25. Liquid droplet or "ionic" fall-out from an offshore waterburst would be much more localised and the radioactivity more intense than that from a landburst, leaving a much smaller fringe area in which decontamination might be of value compared with other remedial measures. It is the considered opinion of the Scientific Advisers' Branch that bursts of megaton weapons on British rivers such as the Clyde or the Thames would not raise enough water to produce fall-out differing significantly from that caused by a landburst and that water droplet fall-out with transferable activity would be infrequent compared with the landburst type of fall-out.

26. In view of the above considerations, the process of decontaminating a typical residential area will be primarily one of mechanical removal of the fall-out particles from the surfaces on which they have been deposited. They may be sucked or swept up into a container and removed to a safe dumping ground or they may be swept into the gutter and washed down into street drains or sumps. On some surfaces it may prove more effective to remove the bulk of the fall-out by dry sweeping or suction methods followed by flushing or fire hosing the surface to remove the remainder of the fall-out.

Surface Loading of Fall-Out Simulant in Area Decontamination Trials

30. Most of the trials with megaton weapons have taken place on coral islands and there is little reliable information on the relationship between the surface deposit of fall-out and the associated reference dose-rate contours, and none at all for megaton landbursts on clay or silicate soil. In one Pacific test the surface fall-out loadings at 8 miles and 60 miles downwind of ground zero of a 5 M.T. burst were estimated respectively at 4.5 and 0.06 gms. per square foot, but no systematic data are available.

Source: WT-1317
(Redwing-Tewa ships YFNB29 and LST611, 1 hr references: 200 and 6 R/hr)

31. In the large scale decontamination trials at Camp Stoneman in California in September, 1956, carriers impregnated with La 140 were used at a surface loading of 25 mgm. per square foot per r.p.h. at H + 1 hours, to simulate fall-out at 1000 to 10,000 r.p.h. at H + 1. It is probably easier to remove fall-out mechanically at the higher surface loadings and it is felt that the above figure is grossly excessive.

Appendix A (I)

Data extracted from Radiological Recovery of Fixed Military Installations

(Report TM 3-225, rev. Apr. 1958.) F.M.I. Sheet I

Performance of Common reclamation methods
for paved areas and buildings

Surface of building or paved area	Standard dose-rate at 1 hour after burst	Residual Numbers for decontamination methods (1)		
		Firehosing or street flushing	Firehosing plus scrubbing	Hot liquid cleaning (2)
Asphaltic Concrete	300 1000 3000	0.07 0.03 0.01	0.05 0.02 0.008	0.02 0.01 0.004
Portland Cement Concrete	300 1000 3000	0.04 0.02 0.008	0.03 0.02 0.006	0.02 0.008 0.003
Tar and gravel roof	300 1000 3000	0.03 0.02 0.01	0.03 0.02 0.01	0.01 0.009 0.004
Composition roofing	300 1000 3000	0.04 0.03 0.01	0.04 0.02 0.01	0.02 0.01 0.005
Wood shingles (tiles)	300 1000 3000	0.17 0.10 0.04	0.13 0.08 0.03	0.06 0.04 0.01
Galvanised steel, corregated	300 1000 3000	0.05 0.02 0.006	0.04 0.01 0.005	0.02 0.006 0.002
Smooth painted surface	300 1000 3000	0.04 0.01 0.004	0.03 0.008 0.003	0.01 0.004 0.001

1. In this report the Residual Number is the fractional dose reduction in the centre of the area after the decontamination of the area plus a surrounding buffer zone of 600 feet width of paved or 200 feet of unpaved. Hence the Residual Number also represents the fraction of the radioactive contamination remaining on the surface.

2. Wet steam 105 psig 320°F (1500 lb/hr) and 1000 gal /hour water at 20 psig.

Appendix A(I)

F.M.I. Sheet 2 (Report TM 3-225, rev. Apr. 1958.)

Notes on procedure and rates of operation

Paved areas and structures

1. Firehosing

The data relate to the clean up of a large area, the fall-out being pushed into a drainage channel at the far edges. The data on rates of operation are much less than would be the case for typical British streets with gutters and drains.

Equipment: Hydrant, booster pump, $2\frac{1}{2}$ inch hose, Y branch feeding two $1\frac{1}{2}$ inch hoses each delivering 100 gallons per minute at 80 p.s.i.g.

Operators: Four men per $1\frac{1}{2}$ inch hose.

Rate: Areas 7,500 sq. ft. per hour per nozzle.

Structures 2,000 sq. ft. per hour per nozzle.

2. Motorised flushing (for large areas only)

Equipment: Flusher delivering 800 gallons per minute at 90 p.s.i.g.

Operators: Two men.

Rate: 35,000 sq. ft. per hour.

3. Hot liquid cleaning

Equipment: Injector Unit, lance and nozzle, steam (1500 lb/hour unit at 105 p.s.i.g. and 320°F): Water (1000 gallons per hour at 20 p.s.i.g.) and Detergent.

Operators: Three men per lance.

Rate: Roofs 2500 sq. ft./hour

Walls 2000 sq. ft/hour.

Appendix A(i)

F.M.I. Sheet 4 *(Report TM 3-225, rev. Apr. 1958.)*

Performance of Common reclamation methods for unpaved land areas

Method	Residual Number (1) for single pass
Ploughing (8 to 10 inches depth)	0.15
Motor Grader scraping (2) (2 to 4 inches cut)	0.07
Motorised scraping (3) (2 to 6 inches cut)	0.15
Filling (to 6 inches depth)	0.15
Motorised scraping plus either ploughing or filling	0.02

(1) See note Sheet 1.

(2) Earth pushed by slanting blade into windrows which are removed from the site.

(3) Earth lifted into a bucket and dumped off site - higher R.N. due largely to spillage.

Appendix A(i)

F.M.I. Sheet 5 *(Report TM 3-225, rev. Apr. 1958.)*

Unpaved Land

1. Ploughing

Three share plough drawn by 125 HP tractor

Rate 35,000 sq. ft. /hour

One operator per gang of ploughs.

2. Motor grader scraping (without time for removal of windrows)

Motor grader with 10 ft. blade.

Rate along a 16 ft. wide roadway one pass on each half of road.

4,000 linear ft. /hour or

64,000 square ft. /hour.

3. Motorised scraper and bulldozer

The scraper takes soil into a bucket and the rate depends on the distance to the dumping ground and on the roughness of the ground.

4. Filling to a depth of 6 inches

Motorised scraper and bulldozer or mechanical shovel and truck.

Rate 3,000 to 10,000 sq. ft. depending on length of haul and nature of soil.

Appendix A(i)

F.M.I. Sheet 6 *(Report TM 3-225, rev. Apr. 1958.)*

LOGISTICS of Decontamination

Method	Equipment Required per 100,000 sq. ft.(1)	Manpower requirements per unit of equipment
Firehosing Areas	0.28 hoses	4 men
Firehosing structures	1.04 hoses	2 men
Motorised street flusher	0.06 flushers	2 men
Firehosing and hand scrubbing on paved areas	0.42 hoses 0.84 brushes detergents	4 men per hose 2 men for scrubbing
Firehosing and scrubbing on structures	1.04 hoses 2.08 brushes 2.08 shovels detergents	4 men per hose 2 men for scrubbing
Hot liquid cleaning of roofs	0.84 lances	4 men
Ploughing	0.06 tractor with plough	1 man
Motor grader scraping	0.033 motor graders	1 man
Motorised scraping	0.42 scrapers	1 man
Filling	0.42 scrapers	1 man
Bulldozing	0.25 dozers	1 man

(1) Based on 48 hours operation of equipment: numbers are also based on 100% efficiency and do not allow time for setup or rest periods. These factors may reduce the efficiency by 15 to 25%.

SYSTEMS ANALYSIS OF RADIOLOGICAL DEFENSE. Kendall D. Moll. Nov. 1958. 124p. (NP-7241) Stanford Res. Inst.

Appendix A(ii)

S.R.I. Sheet 1

Performance Value of Decontamination Measures

(Assuming crew exposure factor of 0.5 i.e. P.F. = 2)

(Data in U.S. gals. = 0.83 British gals.)

Decontamination Measure	Supply needs (per 1000 sq.ft.)	Rate of Coverage sq.ft/man-hr.	Fraction of Radiation Removed	Performance Value (see script)
Roofs				
Firehosing	0.4 gal gas 200 water	1,000	0.9	1,800
Firehosing and scrubbing	0.7 gal gas 1500 water	300	0.93	560
Firehosing and detergent scrubbing	same plus 2 lb detergent	300	0.97	580
Vacuum cleaning	Electricity	-	0.80	-
Paved Areas				
Firehosing	0.15 gal gas 700 water	2,000	0.96	3,800
Firehosing and scrub	0.2 " " 700 water	900	0.97	1,700
Firehosing and detergent scrub	same plus 2 lb detergent	900	0.98	1,800
Motorised flushing	0.3 gal gas 500 water	15,000	0.98	73,000
Motorised sweeping	0.1 gal gas	25,000	0.90	110,000
Unpaved Areas				
Power scraping or bull-dozing	0.5 gal gas	5,000	0.85	21,000
Motor grading	0.2 gal gas	25,000	0.85	110,000
Gang ploughing	0.2 gal gas	20,000	0.85	85,000
Spading (hand)		50	0.85	85
Obstructions (trees, fences etc.)				
Firehosing	0.4 gal gas 2000 water	1,000	0.8	1,600
Firehosing and scrubbing	0.7 gal gas 2500 water	300	0.9	540
Outside Walls				
Firehosing	0.3 gal gas 1300 water	1,500	0.97	2,900
Firehosing and scrub	0.4 gal gas 900 water	500	0.98	980
Firehosing and detergent scrub	same plus 4 lb detergent	500	0.99	990
Vacuum cleaning	Electricity	-	0.97	-

SYSTEMS ANALYSIS OF RADIOLOGICAL DEFENSE. Kendall D. Moll. Nov. 1958. 124p. (NP-7241) Stanford Res. Inst.

Appendix A(ii)

S.R.I. Sheet 2

Distribution of surface area types in a typical American City and their radiation contributions inside shelters

Type of Surface	Shelter in			
	Dwelling houses PF = 2		Commercial Areas Large buildings PF = 10	
	Surface Area sq. ft. per capita	Fraction of the total external radiation penetrating into the shelter from the specified surfaces	Surface Area sq. ft. per capita	Fraction of the total external radiation penetrating into the shelter from the specified surfaces
Roofs	300	0.15	150	0.060
Streets	350	0.06	150	0.005
Other paved areas	300	0.10	150	0.010
Unpaved areas	1,000	0.15	300	0.014
Obstructions (fences, trees, etc.)	400	0.02	100	0.001
Outside Walls	400	0.02	200	0.010
Total exposure as fraction of external		0.50		0.100

SYSTEMS ANALYSIS OF RADIOLOGICAL DEFENSE. Kendall D. Moll. Nov. 1958. 124p. (NP-7241) Stanford Res. Inst.

Appendix A(ii)

S.R.I. Sheet 3

Decontamination Values for dwelling houses (residential areas) and large buildings (commercial areas). Crew exposure factor 0.5 (i.e. P.F.= 2)

Decontamination Measure	Decontamination Value		Hours work per capita to decontaminate		Fraction of radiation removed from the surface	Supply needs per capita to decontaminate all City areas (U.S. gals = 0.83 British gals.
	Houses (residential)	Large Buildings (commercial)	Houses (residential)	Large Buildings (commercial)		
Roofs 300 sq. ft. residential 1500 sq. ft. commercial						
Firehosing	0.90	0.72	0.30	0.15	0.90	0.2 gals gas 900 gal water
Firehosing and detergent scrubbing	029	0.23	1.0	0.5	0.97	0.3 gals gas 700 gal water 3lb detergent
Streets 350 sq. ft. residential 150 sq. ft. commercial						
Firehosing	0.65	0.11	0.18	0.08	0.96	0.08 gal gas 350 gal water
Motorised flushing	12.0	2.2	0.023	0.01	0.98	0.15 " " 250 " "
Motorised sweeping	19.0	3.1	0.014	0.006	0.90	0.05 " "
Other paved areas 300 sq. ft. residential 150 sq. ft commercial						
Firehosing	1.1	0.27	0.15	0.08	0.96	0.07 gal gas 300 gal wate;
Unpaved areas 1000 sq. ft. residential 300 sq ft. commercial						
ower scraping or bulldozing	3.6	1.0	0.2	0.06	0.85	0.7 gal gas
Motor grading	16.0	5.5	0.04	0.01	0.85	0.3 " "
Gang ploughing	13.0	4.2	0.05	0.015	0.85	0.3 " "
Spading (by hand)	0.013	0.004	20.0	6.0	0.85	-
Obstructions 400 sq. ft. residential 100 sq. ft. commercial						
Firehosing	0.080	0.016	0.4	0.1	0.80	0.2 gal gas 1000 gal water
Firehosing and scrubbing	0.027	0.005	1.3	0.3	0.90	0.4 " " 1300 " "
Outside Walls 400 sq. ft. residential 200 sq. ft. commercial						
Firehosing	0.15	0.15	0.27	0.13	0.17	0.2 gal gas 800 gal water
Firehosing and detergent scrubbing	0.05	0.05	0.8	0.4	0.99	0.2 " " 600 " " 2lb detergent

Appendix B(i)

U.S. Studies on the decontamination of representative roofing materials (Reports CRLR 307 and 308)

Panels, 4 ft. x 4 ft. sloped at an angle of 15 degrees except for the built-up tar and gravel roofs which had a slope of 2 degrees, were each contaminated with 210 mgs of a "dust" of Tantalum 182 irradiated to about 5 mc/gm. (Half life 117 days, 1.22 Mev gamma, particle size distribution not available).

The general conclusions were that if water hosing is used at least 40 psig is needed to achieve 90% removal of the contamination.

Vacuum cleaning was also very effective on rough surfaces but it took about three times as long as high pressure hosing.

On smooth surfaces weathering (a 5 to 7 m.p.h. wind) removed 60% of the activity in one day and the wind and rain removed 90% in forty-seven days. Rough surfaces showed 30 to 40% removal of activity by weathering after seven weeks.

The results are shown in R.P. Sheet I and it is to be noted that the roofing materials used are in no way typical of British materials.

Decontamination of Radioactive Ta - 182 dust from various roofing materials.

Reports CRLR 307 and 308 (July/August 1953)

Appendix B(i)

R. P. Sheet I (Roof Panels)

Decontamination Method	Surface Material	Total Time Minutes unless stated	Total water gallons	% Decontamination
Low pressure hosing 8 p s i g	Rolled asphalt	2	10	98
	strip shingle	4	20	84
	corrugated metal	2	10	95
	built-up tar and gravel	4	20	23
Low pressure hosing and brushing	r. a.	2	10	96
	s. s.	3	15	88
	c. m.	1	5	98
	t. and g.	4	20	44
Hosing 24 p s i g	t. and g.	45 sce.	6.5	32
Firehosing 40 p s i g	t. and g.	60 sec.	12.5	98
High pressure hosing 50 p s i g	r. a.	15 sec.	3.5	88
	s. s.	30 sec.	7.0	96
	c. m.	15 sec.	3.5	100
	t. and g.	60 sec.	14	95
H. P. hot water and steam (Seller's Unit) 90 p s i g hot water 8.3 gpm.	r. a.	30 sec.	4.2	94
	s. s.	1 min.	8.4	69
	c. m.	30 sec.	4.2	97
	t. and g.	1 min.	8.4	91
Vacuum cleaning	r. a.	2.5		99
	s. s.	2.5		91
	c. m.	1.5		97
	t. and g.	2.5		98
Dry sweeping	r. a.	2		82
	s. s.	2		0.9
	c. m.	2		96
	t. and g.	2		12

Decontamination of Radioactive Ta - 182 dust from various roofing materials.

Reports CRLR 307 and 308 (July/August 1953)

Appendix B(ii)

Plumb Bob Trial on Unpaved Ground

In this trial an area about 1 mile from ground zero of a tower burst bomb was contaminated to a peak intensity of about 60 r.p.h. A square 500 ft. by 500 ft. was monitored by recorders who came out of a nearby underground shelter and it was decontaminated starting at about H + 48 hours by a team of men with equipment brought from outside the contaminated area. It was again monitored after decontamination.

The ground consisted of stony desert from which boulders and larger stones had been scraped before the trial. It therefore represented the most difficult type of unpaved surface to clean by earth moving techniques.

Equipment used

4 motor graders (2 inch cut)
2 motorised scrapers
1 bulldozer

Procedure A 40' x 40' square was first cleared by the motor graders: this was enlarged to 60' x 60' by a 10' pass all round (pushing windrows to the periphery) and finally extended to 100' x 100'. Several trips with the scrapers were necessary to remove the windrows.

Finally a 200' wide buffer zone was cleared around the 100' x 100' area making a total cleared area of 500' x 500'.

Another 100' x 100' area was cleared in the same way but a 3' high earth barrier was built up round its periphery instead of the buffer zone.

The results of the decontamination are shown below in terms of the percentage residual dose-rate at the centre of the square.

Area cleared	Average % residual dose-rate at centre of the cleared square
40' x 40'	39
60' x 60'	32
100' x 100'	24
500' x 500'	16
After second pass over central 100' x 100' area	11
Centre of 100' x 100' Area with 3 ft. high earth barrier around it.	16

/Duration

U.S.A.E.C. Report ITR 1464 (14/2/58)

Operation Plumbbob (Nevada, summer 1957)

Evaluation of Countermeasures System Components and Operational Procedures (CD 11605)

Duration of task of clearing 500' x 500' area - 3 hours

Average Protective Factor of operators of the equipment - 5

(from doses recorded on their film badges.)

U.S.A.E.C. Report ITR 1464 (14/2/58)

Operation Plumbbob (Nevada, summer 1957)

Evaluation of Countermeasures System Components and Operational Procedures (CD 11605)

Appendix B(iii)

Camp Stoneman Trials September 1956

The large deserted Military Camp Stoneman was used for this trial Large areas of paved ground with different types of surface and huts with different types of roofing material were contaminated to an extent which was estimated to correspond to 1000 and 10,000 r.p.h. at H + 1 hours.

For this purpose a surface loading of fall-out simulant of 25 mg per sq. ft. per 1 r.p.h. at H + 1 i.e. 25 gms/sq. ft. to represent 100 r.p.h. and 250 gms/sq.ft. to represent 10,000 r.p.h. at H + 1 were chosen. It was later considered that this was much too heavy a contamination and the results were interpolated to 3000 r.p.h. at H + 1 but it was felt that they could not be extrapolated down to 300 r.p.h. at H + 1 without serious misgivings.

Two types of fall-out simulant were used, a dry powder and a slurry but both were in fact typical only of a landburst weapon as there was no transfer of radioactivity from the carrier particles into the solution or on to the surface contaminated.

The fall-out simulants were based on a solution of Lanthanum - 140 (half life 40.2 hours, 1.2 Mev gamma emission) which was mixed with the appropriate carrier material. The powdered simulant consisted of Camp Stoneman loam soil (40,000 lb used) impregnated with the La 140 solution: The slurry (30,000 lbs) was produced by impregnating dried harbour mud from San Francisco bay with the La - 140 solution and then adding an equal weight of water.

The results of various decontamination procedures on different types of surface in terms of effectiveness, rate of operation and man-hours effort are shown in Tables 5.1 to 5.6 reproduced from Report U.S. NRDL - TR- 196. The planning rates and effort include time required to set up the equipment and to move it from area to area and also include an adjustment for an estimated 75% efficiency in the productive effort.

Table 5.7 is also included: it contains data estimated on a similar basis for transferable or ionic fall-out from an off-shore water burst. The data in Table 5.7 have been estimated from laboratory experiments and some very limited data from two water burst trials.

U.S. NRDL - TR - 196 (27.12.57)

Cost and Effectiveness of Decontamination Procedures for Land Targets (Test at Camp Stoneman, California, September 1956) (CD 12030)

U.S. NRDL - TR - 196 (27.12.57)

Cost and Effectiveness of Decontamination Procedures for Land Targets (Test at Camp Stoneman, California, September 1956) (CD 12030)

Appendix B(iii)

Camp - Stoneman Trials

Table 5.1 Expected Recovery Performance on Asphaltic Concrete Exposed to Dry Contaminant

	1000 r/hr Initial Standard Dose Rate					3000 r/hr Initial Std Dose Rate				
PROCEDURE	Resid'l Std. Dose Rate r/hr	Effectiveness[b] Residual Number	Plann'g Rate 1000 ft²/hr	No. of men	Effort[c] Man hrs/1000 ft²	Resid'l Std. Dose Rate r/hr	Effectiveness[b] Residual Number	Plann'g Rate 1000 ft²/hr	No. of Men	Effort[c] Man hrs/1000 ft²
Column	1	2	3	4	5	1	2	3	4	5
Motorized Flushing	8-16	.01	35	2	0.06	18-32	.006-.01	35	2	0.06
Firehosing	1-100[d]	.04	15	6-8	0.4-0.5	16-94[d]	.02	15	6-8	0.4-0.5
FH-HSD-FH[a]	12-19	.01-.02	10	11-13	1.1-1.3	26-38	.01	10	11-13	1.1-1.3

Table 5.2 Expected Recovery Performance on Portland Cement Concrete Exposed to Dry Contaminant

	1000 r/hr Initial Standard Dose Rate					3000 r/hr Initial Std Dose Rate				
PROCEDURE	Resid'l Std. Dose Rate r/hr	Effectiveness[b] Residual Number	Plann'g Rate 1000 ft²/hr	No. of Men	Effort[c] Man hrs/1000 ft²	Resid'l Std. Dose Rate r/hr	Effectiveness[b] Residual Number	Plann'g Rate 1000 ft²/hr	No. of Men	Effort[c] Man hrs/1000 ft²
Column	1	2	3	4	5	1	2	3	4	5
Motorized Flushing	6-12[e]	.01	35	2	0.06	8-27	.003-.009	35	2	0.06
Firehosing	19-34	.02-.03	15	6-8	0.4-0.5	18-35	.006-.01	15	6-8	0.4-0.5
FH-HSD-FH[a]	6-11	.01	10	11-13	1.1-1.3	9-14	.003-.005	10	11-13	1.1-1.3

[a] Firehosing plus handscrubbing with detergent followed by a second firehosing.

[b] Residual number, as a measure of effectiveness, is the ratio of residual standard dose rate/initial standard dose rate:

[c] Effort, in man hr/1000 ft², results from dividing the number of men involved by the planning rate: $\frac{\text{column 4}}{\text{column 3}}$

[d] Poor specific activity data provided an extremely large confidence interval.

[e] This data from MF-MS-MF test results, and it is assumed that the MS operation did not add to the decontamination effectiveness.

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Appendix B(iii)

Camp - Stoneman Trials

Table 5.3 Expected Recovery Performance on Asphaltic Concrete Exposed to Slurry Contaminant

PROCEDURE	1000 r/hr Initial Standard Dose Rate					3000 r/hr Initial Std Dose Rate				
	Resid'l Std. Dose Rate	Effec-tiveness[b]	Plann'g Rate	No. of Men	Effort[c]	Resid'l Std. Dose Rate	Effec-tiveness[b]	Plann'g Rate	No. of Men	Effort[c]
	r/hr	Residual Number	$\frac{1000\ ft^2}{hr}$		$\frac{Man\ hrs}{1000\ ft^2}$	r/hr	Residual Number	$\frac{1000\ ft^2}{hr}$		$\frac{Man\ hrs}{1000\ ft^2}$
Motorized Flush-ing	44-53	.05	28	2	0.07	47-57	.02	28	2	0.07
Firehosing	24-70	.03-.07	9	6-8	0.7-0.9	50-74	.02	9	6-8	0.7-0.9
FH-HSD-FH[a]	34-41	.04	9	11-13	1.2-1.4	36-42	.01	9	11-13	1.2-1.4

Table 5.4 Expected Recovery Performance on Portland Cement Concrete Exposed to Slurry Contaminant

PROCEDURE	1000 r/hr Initial Standard Dose Rate					3000 r/hr Initial Std Dose Rate				
	Resid'l Std. Dose Rate	Effec-tiveness[b]	Plann'g Rate	No. of Men	Effort[c]	Resid'l Std. Dose Rate	Effec-tiveness[b]	Plann'g Rate	No. of Men	Effort[c]
	r/hr	Residual Number	$\frac{1000\ ft^2}{hr}$		$\frac{Man\ hrs}{1000\ ft^2}$	r/hr	Residual Number	$\frac{1000\ ft^2}{hr}$		$\frac{Man\ hrs}{1000\ ft^2}$
Motorized Flushing	35-52	.04	28	2	0.07	43-56	.01-.02	28	2	0.07
Firehosing	36-55[d]	.04	9	6-8	0.7-0.9	36-55[e]	.01-.02	9	6-8	0.7-0.9
FH-HSD-FH[a]	8-62[d]	.01-.06	9	11-13	1.2-1.4	8-62[e]	.003-.02	9	11-13	1.2-1.4

[a]Firehosing plus handscrubbing with detergent followed by a second firehosing.

[b]Residual number, as a measure of effectiveness, is the ratio of residual standard dose rate/initial standard dose rate:

[c]Effort, in man hr/1000 ft^2, results from dividing the number of men involved by the planning rate: $\frac{\text{column 4}}{\text{column 3}}$

[d]Inconsistent results provided the wide range.

[e]The r[illegible]ge was expanded and adjusted to equal the width and magnitude of the 1000 r/hr values.

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Appendix B(iii)

Camp Stoneman Trial

Table 5.5 Expected Recovery Performance on Roofs Exposed to Dry Contaminant

SURFACE and PROCEDURE	1000 r/hr Initial Standard Dose Rate					3000 r/hr Initial Std Dose Rate				
	Resid'l Std. Dose Rate	Effectiveness[b]	Planning Rate	No. of Men	Effort[c]	Resid'l Std. Dose Rate	Effectiveness[b]	Planning Rate	No. of Men	Effort[c]
	r/hr	Residual Number	1000 ft²/hr		Man hrs/1000 ft²	r/hr	Residual Number	1000 ft²/hr		Man hrs/1000 ft²
Column	1	2	3	4	5	1	2	3	4	5
Corrugated Metal										
Firehosing	29	.03	3.9	2	0.5	30	.01	3.9	2	0.5
FH-HSD-FH[a]	5	.005	4.8	5	1.0	12	.004	3.9	5	1.3
Tar and Gravel										
Firehosing	38	.04	1.5	4	2.7	38	.015	1.5	4	2.7
FH-HSD-FH[a]	10	.01	1.8	7	3.9	31	.01	1.8	7	3.9
Roll Roofing										
Firehosing	54	.05	3.0	2	0.7	54	.02	3.0	2	0.7
FH-HS-FH	15	.015	3.9	5	1.3	30	.01	3.3	5	1.5
Composition Shingle										
Firehosing	60	.06	3.0	2	0.7	70	.02	3.0	2	0.7
FH-HS-FH	31	.03	3.0	5	1.7	46	.015	2.7	5	1.8
Wood Shingle										
Firehosing	100	.10	2.1	2	1.0	200	.07	2.1	2	1.0
FH-HS-FH	50	.05	1.5	5	3.3	100	.03	1.5	5	3.3

[a] Firehosing plus handscrubbing with detergent followed by a second firehosing.
[b] Residual number, as a measure of effectiveness, is the ratio of the residual standard dose rate/intial standard dose rate:
[c] Effort, in man hrs/1000 ft², results from dividing the number of men involved by the planning rate: column 4/column 3.

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Appendix B (iii)

Camp - Stoneman Trials

Table 5.6 Expected Recovery Performance on Roofs Exposed to Slurry Contaminant

	1000 r/hr Initial Standard Dose Rate					3000 r/hr Initial Std Dose Rate				
Surface and Procedure	Resid'l Std. Dose Rate	Effec-tiveness[b]	Plann'g Rate	No. of Men	Effort[c]	Resid'l Std. Dose Rate	Effec-tiveness[b]	Plann'g Rate	No. of Men	Effort[c]
	r/hr	Residual Number	1000 ft^2/hr		Man Hrs/1000 ft^2	r/hr	Residual Number	1000 ft^2/hr		Man hrs/1000 ft^2
Column	1	2	3	4	5	1	2	3	4	5
Corrugated Metal										
Firehosing	30	.030	2.7	2	0.7	38	.013	2.7	2	0.7
FH-HSD-FH[a]	7	.007	3.0	5	1.7	17	.006	2.7	5	1.8
Tar and Gravel										
Firehosing	55	.055	1.5	4	2.7	55	.018	1.5	4	2.7
FH-HSD-FH	45	.045	1.8	7	3.9	50	.017	1.8	7	3.9
Roll Roofing										
Firehosing	120	.12	1.8	2	1.1	120	.04	1.8	2	1.1
FH-HS-FH	55	.055	3.0	5	1.7	55	.018	2.7	5	1.8
Composition Shingle										
Firehosing	250	.25	1.8	2	1.1	250	.083	1.8	2	1.1
FH-HS-FH	170	.17	2.4	5	2.1	200	.067	2.4	5	2.1
Wood Shingle										
Firehosing	250	.25	1.5	2	1.3	250	.083	1.5	2	1.3
FH-HS-FH	170	.17	0.9	5	5.6	200	.067	0.9	5	5.6

[a]Firehosing plus handscrubbing with detergent followed by a second firehosing.

[b]Residual number, as a measure of effectiveness, is the ratio of the residual standard dose rate/initial standard dose rate.

[c]Effort, in man hrs/100 ft^2, results from dividing the number of men involved by the planning rate: column 4/column 3.

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Appendix B(iii)

Miscellaneous Laboratory and Weapon Trials data on Offshore Waterburst fall-out (activity transferable)

Table 5.7 Expected Recovery Performance on Paved Areas and on Roofs Exposed to Wet (ionic) Contaminant

Surface	Procedure	Range of[b] Effectiveness (Residual Number)	Planning Rate (1000 ft^2 hr)	No. of Men	Range of Effort[c] (Man hrs/1000 ft^2)
Pavements Concrete or Asphalt	Motorized Flush'g	.50 - .75	27	2	.07
	Firehosing	.55 - .85	9	6 - 8	0.7 - 0.9
	FH-HSD-FH[a]	.35 - .55	9	11 - 13	1.2 - 1.4
	Heáter Planer[d]	.04 - .06	4 - 8	3 - 4	.4 - 1.0
Roofs					
Tar and Gravel	Firehosing	.20 - .30	1.5	4	2.7
	FH-HSD-FH[a]	.05 - .15	1.8	7	3.9
Roll Roofing	Firehosing	.65 - .85	3.0	2	0.7
	FH-HS-FH	.20 - .50	2.4	5	2.1
Comp. Shingles	Firehosing	.65 - .85	3.0	2	0.7
	FH-HS-FH	.25 - .55	2.4	5	2.1
Corrg. Metal	Firehosing	.60 - .90	2.4	2	0.8
	FH-HS-FH	.40 - .55	1.8	5	2.8
Wood Shingles	Firehosing	.75 - .85	2.4	2	0.8
	FH-HS-FH	.35 - .75	1.8	5	2.8

[a]Firehosing plus handscrubbing with detergent followed by a second firehosing.

[b]Residual number, as a measure of effectiveness, is the ratio of the residual standard dose rate/initial standard dose rate.

[c]Effort, in man hours/1000 ft^2, results from dividing the number of men involved by the planning rate.

[d]Restricted to surface removal of asphalt paving only. Greater rate based on use of skip loader for truck with debris. Lesser rate relies on 2 laborers to shovel debris into truck. The results of this destructive decontamination method shows that surface removal techniques are required to achieve low residual numbers.

U.S. NRDL - TR - 196 (27.12.57)

Cost and Effectiveness of Decontamination Procedures for Land Targets (Test at Camp Stoneman, California, September 1956) (CD 12030)

CD/SA 96
Addendum

Home Office
Scientific Adviser's Branch

The Decontamination of Residential Areas

Application of U.S. performance data to a London District

J. McAulay

Introduction

1. American data on the decontamination of large areas are reviewed in Paper CD/SA 96. The object of the present supplement is twofold:

(i) To describe a method and chart for quick assessment of the equipment, manpower and time needed to decontaminate the pavements and streets in any built-up area under the wide range of conditions likely to be encountered in nuclear warfare and

(ii) To apply the chart and the U.S. experimental data to the decontamination of a typical heavily populated residential area about 7 miles south of the centre of London.

2. CD/SA 96 also mentioned British plans for public control in a contaminated area to avoid radiation sickness and possible death. These plans assume an initial period of up to 48 hours in a radiological refuge: for the following week or two, when possible, the daily periods of exposure out-of-doors to perform essential services or to get necessities for the family, should be limited to 2 hours in the more heavily contaminated and 4 hours in the less heavily contaminated zones. It is also shown that about two thirds of the total dose accumulated by people who will have to remain in the contaminated zones will be acquired during these short outdoor periods. The decontamination of access routes from houses to the local distribution centres in built-up areas therefore offers a possibility of reducing the subsequent dose to the population by a factor of two or more and of permitting an earlier resumption of normal community life and activities.

3. The effort required to decontaminate a built-up area will depend not only on the local intensity of radiation at the time but also on the water supplies and on the type and amount of equipment, particularly of mechanised equipment, available. In most European towns equipment will be the limiting factor which will determine when the work can be started, how long it will take and how many men will be needed within the restriction that none of them should get more than a limited and agreed dose of gamma radiation.

4. The inner commercial centres of towns, where the resident population is small, frequently have pavements wide enough to permit the passage of mechanised street cleaning equipment in spite of obstructions such as poles, lampposts, post boxes etc. near the pavement edge. In many residential districts the pavement width may be 7 ft. or less so that mechanised equipment might have to be confined to the street: in such cases a small contribution from the residents would be required to brush or wash contamination from the sidewalks and the pavement in front of each house into the street gutter.

5. Major limiting factors are the starting time t, and the working shift length i.e. the number of hours $\Delta T = t_1 - t_2$ that men can work in a contaminated area before they get the allowed dose of radiation D_a. It is assumed that the gamma dose-rate will decay as a function of $t^{-1.2}$ during the first few weeks after the nuclear detonation. If R_1 is the one hour reference dose-rate and if f the factor of protection afforded by any vehicle used for decontamination, then the dose D_a which may be incurred from t_1 to t_2 hours is

$$D_a = \frac{5\ R_1}{f} \left\{ t_1^{-0.2} - t_2^{-0.2} \right\}$$

In the more heavily contaminated areas D_a may be accumulated in a single short work shift but in less heavily contaminated areas it will be possible for individuals to do repeated shifts separated by 8 or 12 hour rest periods: the work will take longer but will require less equipment and fewer men.

The allowed dose D_a

6. In the U.K. a Wartime Emergency Dose (WED) limit of 75r (100r under exceptional circumstances) has been accepted for Civil Defence life-saving operations. A limit has not yet been officially specified for decontamination operations and in this paper the 75r limit has been assumed to be applicable to the decontamination of access routes to permit the restoration of the essential activities of the community. Clearly, therefore, if the maximum use is to be made of specially trained men, the decontamination personnel must be given the best possible radiological protection during the early period of high dose-rate and rapid decay.

Transit dose

7. Decontamination crews will presumably operate from radiological shelters within the same district and they will not have to travel more than a few miles in an automobile at a speed of at least 30 m.p.h. Transit doses will therefore be negligible compared with the allowed dose D_a except in very heavily contaminated areas or where distances are more than 2-3 miles when the transit dose D_{trans} will have to be deducted from D_a. It may be calculated with sufficient accuracy for decontamination operations from the estimated transit time multiplied by the mean dose-rate over the distance to be travelled.

Starting time t, and duration of working shift (t_1-t_2)

8. Assuming a mean protective factor "f" over the transit and working time

$$\left(D_a - D_{trans}\right) f = 5R_1 \left\{ t_1^{-0.2} - t_2^{-0.2} \right\}$$

All variables other than time t can be grouped into one parameter

$$K = \left(\frac{D_a - D_{trans}}{5R_1}\right) f = \left(t_1^{-0.2} - t_2^{-0.2} \right)$$

In Fig. 1 the shift duration $\Delta T = t_1 - t_2$ has been plotted against the starting time t_1 for a family of curves covering a range of likely or useful values of K. Fig. 1 can be used to determine any one of the variables ΔT, t_1 and K (and hence also of D_a) given the other two.

Heavily populated residential area in London

9. Details of a residential area to the north of Croydon and 7 miles south of the centre of London are given in Table 1. It consists mainly of rows of two or three storey terraced houses in streets at right angles to a main shopping and business thoroughfare: the latter consists of three storey terraced buildings with residences frequent in the upper floors.

Table I

Normal population	about 16,000
Total area (about 160 hectares)	399 acres
Streets length	73,000 ft.
Pavement widths	7 ft.
Area streets and pavements (67 acres)	2.92×10^6 sq. ft.

Other details

Open spaces other than house gardens				20.0 acres
Church buildings	(5)	plan	area	0.67 "
School buildings	(3)	"	"	0.58 "
Halls	(4)	"	"	0.47 "
Public Library	(1)	"	"	0.09 "
Pavilions and Club Houses	(4)	"	"	0.24 "
Houses and shops	(4,453)	"	"	63.70 "
Balance: back and front gardens of houses and courts of larger buildings				about 246 acres.

Decontamination techniques and types of equipment

10. The U.S. data related to the decontamination of a large paved area (airfield) from which the fall-out was pushed by mechanised road sweepers into windrows and carted away to a prepared dump or it was washed into drainage channels, round the periphery of the area by motorised flushing machines or hand operated fire hoses.

11. There is little reliable information on the likely density of fall-out deposits in relation to intensity of radiation. In this paper a range of 20 to 0.05 gms per sq. ft. is assumed (20 to 0.05 mg/cm^2). Thus over the pavements and streets of the London district under consideration, the amount of fall-out to be removed could range from 60 metric tons to a fraction of one ton.

12. British towns have a street drainage system which would greatly facilitate the disposal of all but the heaviest fall-out in sweeping it into the street gutters and then flushing or hosing it down into the drains. The U.S. rates of operation would be applicable to mechanised road sweepers with collector boxes and to motorised flushers, because of the time needed to empty the boxes or to fill the large water tanks. It is considered however that the U.S. rates for fire-hosing from a hydrant or pump and emergency reservoir would be too slow for British streets in which a road sweeper pushes the fall-out into the gutters and it is then hosed into the drains using the trailer pumps of the auxiliary fire service. (For very heavy fall-out the use of road sweepers with collector boxes would be preferable).

13. The performance data assumed in this paper for decontamination assessment are shown in Table 2.

Table 2

Equipment	Effectiveness % contamination removed	Number of crew per Unit	Rate of Operation sq. ft. per hour/unit	Assumed Protective Factor
A. Mechanised road sweeper U.S.	90	1	25,000	3
B. Motorised flusher (U.S.) 800 U.S. g.p.m. at 90 p.s.i.g.	98	2	30,000	2
C. Firehosing (U.S.) 100 g.p.m. at 80 p.s.i.g.	96	4 per nozzle	7,500	1.25 (see para 23)
D. U.K. Combined road sweeper and firehosing	96?	1 4 per nozzle	80,000 20,000	3 1.25

Application to a London District (Table 1)

(Area of streets and pavements 2.92×10^6 sq. ft)
Normal population 16,000

A. Mechanised road sweeper (U.S.) Crew 1. Da = 75r f = 3

14. If the job had to be completed in a single shift of 8 hours, fifteen machines and fifteen operators would be needed. If it could wait until decay permitted each man to do a repeat 8 hour shift after 12 hours rest then eight machines and eight men would be needed.

15. Estimated from the chart Fig. 1, the earliest starting times and the shift times for different one hour reference dose-rates are shown in Table 3.

Table 3

Mechanised road sweepers f = 3

R r.p.h.	K	Earliest shift hours	D_a r per man
Single 8 hour shift, 15 sweepers, 15 men			
10,000	.0045	H + 125 to H + 133	75
3,000	.015	H + 46 to H + 54	75
1,000	.045	H + 16 to H + 24	75
Two 8 hour shifts each for 8 men, 8 sweepers			
1,000	.030	H + 24 to H + 32	50)
	.0157 (from Fig.1)	H + 44 to H + 52	26) 76
500	.060	H + 12 to H + 20	50)
	.022 (from Fig.1)	H + 32 to H + 40	19) 69

16. If only a single machine were available and it was used continuously, the decontamination would take 117 hours. In an area of R_1 = 1000 r.p.h. and for D_a = 75 and f = 3, K = 0.045, it can be seen from Fig. 1 that if necessary a first 4 hour shift could start at H + 10 hours and decontamination could be completed by D + $5\frac{1}{4}$ days. A total of eight to nine men would be needed, working in 4 hour shifts with 12 hour rest periods between, each being replaced by another as he reached his limit of 75r. Even so, at least three of the nine men would get less than half the allowed dose with a balance of $1\frac{1}{2}$ "radiological lives" for other work.

17. It is clearly an advantage to use at least two mechanised sweepers and more where $R_1 \gg 1000$ r.p.h. since there is little difference between manpower needed to complete the work with eight machines during the third day and with one machine during the sixth day.

B. Motorised flusher (U.S.) Crew 2. D_a = 75r. f = 2

18. This technique is dependent on an ample supply of water. The water requirement is quoted as 500 U.S. gal. per 1000 sq. ft. so that for the total area of 2.92×10^6 sq. ft. of streets and pavements, 1.5×10^6 U.S. gal or 5700 m^3 of water would be needed (1 U.S. gal = 3.78 litres).

19. If the job had to be completed in a single working shift of 8 hours, 12 machines (24 men) would be needed. If it could wait until decay permitted each crew to work an additional shift (preferably in daylight) with a 12 hour rest period between, then the work could be done with 6 machines (24 men). The earliest starting times for different one hour reference dose rates have been estimated from Fig. 1 and are shown in Table 4.

Table 4

Motorised flusher $f = 2$

Single 4 or 8 hour shift for 24 men in 12 machines			
R_1 r.p.h.	K	Earliest shift hours	Da r/man
10,000	.0030	H + 185 to H + 189	75
3,000	.010	H + 65 to H + 73	75
1,000	.030	H + 24 to H + 32	75
Two 4 or 8 hour shifts each for 24 men in 6 machines			
1,000	.020	H + 35 to H + 43	50)
			) 80
	.012 (from Fig.1)	H + 55 to H + 63	30)
500	.040	H + 18 to H + 26	50)
			) 73
	.0184	H + 38 to H + 46	23)

20. If only one motorised flusher were available and it was used continuously, decontamination of the 2.92×10^6 sq. ft. of streets and pavement would take about 98 hours. In an area where $R_1 = 1000$ r.p.h. and for Da = 75 and $f = 2$, $K = 0.030$ it can be seen from Fig. 1 that a first 4 hour shift could start at H + 13 hours. A rough estimate can be made from Fig. 1 that not more than 20 men would be needed to decontaminate the whole area by about D + $4\frac{3}{4}$ days.

C. Firehosing by hand (U.S.)

21. This technique of decontamination would have to be used where no equipment other than that of the fire service was available. The U.S. data are based on the use of $1\frac{1}{2}$ inch hoses fitted with $\frac{5}{8}$ inch nozzles, delivering 100 U.S. gals. per minute at 80 p.s.i.g, with an overall manpower requirement of 4 men per nozzle and a cleaning rate of 7,500 sq. ft. per nozzle per hour.

22. The total water requirement would be about 2.4×10^6 U.S. gals. (9100 m^3) which is about 60% greater than that needed for motorised flushing. Lack of water would thus be a major limitation on the speed of decontamination in districts with only firehosing equipment.

23. In a heavily populated district where buildings are often continuous on both sides of the street, there will be a significant reduction in the average dose-rate because of the areas already cleaned. The fractional reduction will depend also upon the depth of front gardens and the roof areas in line of sight from operations in the roadway. In the selected London district (Table 1) front gardens were 5 ft. deep and in 2 storey houses the amount of visible roof was equivalent to the addition of 15 ft. to either side of the road i.e. a centre strip of 40 ft. in a total equivalent width of 80 ft. would be cleaned and this should reduce the dose-rate ultimately to considerably less than half its original value. Since two and probably three out of the crew of four men/nozzle will be working most of the time manning the pump and hauling the hose in a

cleaned part of the road, an average protective factor of 1.25 has been assumed for men engaged in firehosing streets and pavements in a built-up area.

24. If the job had to be completed in a single shift of 8 hours, 50 nozzles, 200 men and a total rate of water consumption of 0.3 million U.S. gals/hour (1130 m^3/hour).

Table 5

Firehosing single 8 hour shift f = 1.25
50 nozzles 200 men

R_1 r.p.h.	K	Shift hours	Dose r/man
3,000	.0063	H + 98 to H + 106	75
1,000	.0188	H + 37 to H + 54	75
500	.0375	H + 19 to H + 27	75

25. If 25 nozzles and hoses were available, the teams could work in two consecutive shifts for a dose of 150r, the length of each shift being arranged so that each gets a dose of 75r. Here $K_2 = \frac{150 \times 1.25}{5R_1}$ and $K_1 = \frac{75 \times 1.25}{5R_1}$.

The whole district could then be decontaminated in $\frac{2.92 \times 10^6}{25 \times 7.5 \times 10^3}$ or about

$15\frac{1}{2}$ hours.

Table 6

Firehosing Consecutive Shifts f = 1.25
25 nozzles 2 x 100 men

R_1	K_2	Consecutive Shift hours	K_1	Individual Shift hours
3,000	.0125	H + 89 to H + 104 (15 hours)	.0063 .0063	T_1 $7\frac{1}{4}$ T_2 $7\frac{3}{4}$
1,000	.0375	H + 32 to H + 47 (15 hours)	.0188 .0188	T_1 $6\frac{1}{2}$ T_2 $8\frac{1}{2}$
500	.075	H + 16 to H + 31 (15 hours)	.0375 .0375	T_1 $6\frac{1}{2}$ T_2 $8\frac{1}{2}$

D. Proposed British combined technique

26. This would be applicable to all but the heaviest fall-out deposits (i.e. much above $R_1 = 1000$). The decontamination would be carried out using a standard type road sweeping machine (without a collector box), which would sweep the fall-out into the street gutters and it would then be swept with firehoses down into the street drains: four $1\frac{1}{2}$ inch firehoses (each with a $\frac{5}{8}$ inch nozzle) could be fed by one existing type trailer pump of the British auxiliary fire service.

27. The road sweeper is assumed to afford protection by a factor $f = 3$. The rate of forward travel is normally just over 3 m.p.h. and assuming six passes over 40 ft. width of street and pavement and allowing about 25% of the time for servicing, the overall cleaning rate will be 80,000 sq. ft. per hour. The time required to sweep the whole area will be thus $2.92 \times 10^6/8 \times 10^4 = 36\frac{1}{2}$ hours.

28. Since firehosing in the open will follow behind the road sweeper it will not be realistic to start* decontamination earlier than about H + 16. For a one hour reference dose-rate, $R_1 = 1000$ r.p.h., Da = 75 $f = 3$, it can be estimated from Fig. 1 that three men each doing two 6 hour shifts with 12 hour rest period between, could sweep the whole area in about 36 hours getting doses of about 50, 40 and 30r respectively.

29. Firehosing would be started about H + 17: an average protective factor $f = 1.25$ (see paragraph 23) is assumed for men engaged in firehosing. A forward speed of about 1000 ft./hour per nozzle for driving fall-out along the street gutter down into the drains is considered to be reasonable. With one nozzle to each gutter and a paved width of 40 ft. this is equivalent to a cleaning rate of 20,000 sq. ft. per hour per nozzle.

30. One fire service trailer pump feeding 4 hoses and nozzles could keep pace with the road sweeper and clean the district in about 36 hours. In general, shifts of about 4 hours duration with a 12 hour rest interval will be preferable for this heavy manual work and unless illumination can be provided at night it will be desirable to limit firehosing to the hours of daylight.

31. Water consumption by the combined road sweeper and fire hosing technique would be $100 \times 60 \times 36 \times 4 = 0.86 \times 10^6$ U.S. gals or 3250 m^3 which, as one would expect, is considerably less than the amount needed either for the motorised flusher or for the firehosing technique alone.

32. If firehosing were carried out continuously with 4 nozzles from H + 17 to H + 53 (i.e. one hour behind the road sweeper), ~~6~~ 9 crews each of 16 men (total 144 ~~96~~ men) working in ~~4~~ 3 hour shifts with 12 hours off, would be needed and of these, three ~~one~~ crews of 16 men would receive only about one ~~third~~ half of the allowed dose.

33. If firehosing were suspended during the night 5 crews of 16 men (total 80 men) using 4 nozzles could probably complete the decontamination by D + $3\frac{1}{2}$ days - alternatively with two trailer pumps and 8 nozzles and 160 men, appropriate daylight shifts could be worked out from Fig. 1 to have the work completed by about D + $2\frac{1}{2}$ days.

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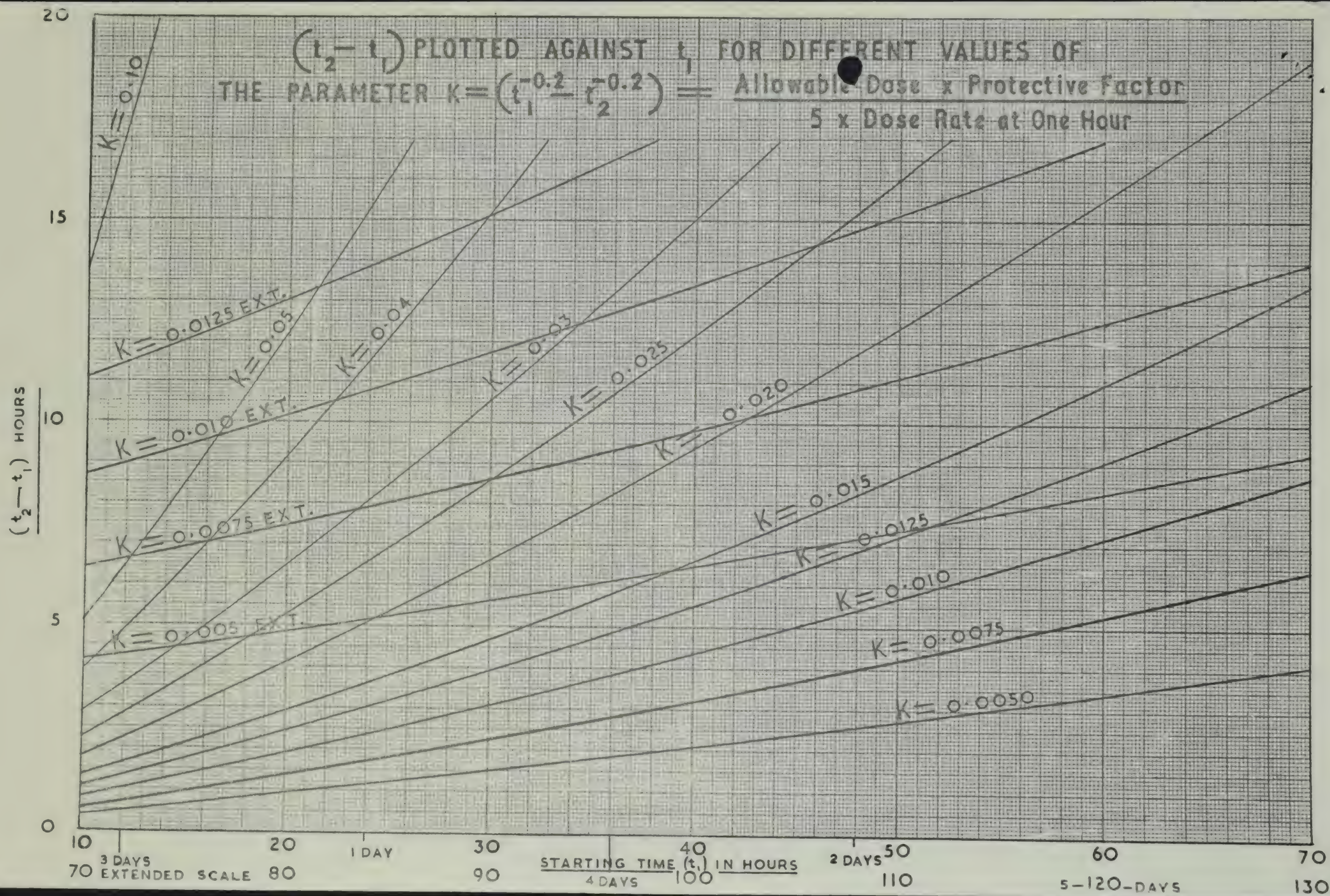
*In heavily contaminated areas the work should not start before 48 hours but shortage of equipment may make it desirable to start as soon as possible in some districts so that others will not have to remain contaminated for excessively long periods.

Table 7

Comparative Summary

Paved Area to be Decontaminated
2.92 x 10^6 sq. ft. (= 27 hectares)
for R_1 = 1000 r.p.h. and Do = 75r

Technique	Equipment	Man hours	Time
A. Mechanised road sweeper (U.S.)	15 sweepers	15 x 8 = 120	H + 16 to 24
B. Motorised flusher (U.S.)	12 flushers	24 x 8 = 192	H + 24 to 32
C Firehosing (U.S.)	50 Nozzles	200 x 8 = 1600	H + 37 to 45
D. Combined U.K. road sweeper, trailer pump and firehoses	1 sweeper 1 trailer pump 4 nozzles	3 x 12 = 36 9 x 16 x 4 = 596 total 612	H + 17 to 53



$(t_2 - t_1)$ PLOTTED AGAINST t_1 FOR DIFFERENT VALUES OF
THE PARAMETER $K = \left(t_1^{-0.2} - t_2^{-0.2}\right) = \frac{\text{Allowable Dose x Protective Factor}}{\text{5 x Dose Rate at One Hour}}$
$(t_2 - t_1)$ HOURS
STARTING TIME (t_1) IN HOURS
EXTENDED SCALE
3 DAYS
1 DAY
2 DAYS
4 DAYS
5–120–DAYS
K = 0·10
K = 0·05
K = 0·04
K = 0·03
K = 0·025
K = 0·020
K = 0·015
K = 0·0125
K = 0·010
K = 0·0075
K = 0·0050
K = 0·0125 EXT.
K = 0·010 EXT.
K = 0·0075 EXT.
K = 0·005 EXT.
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DECONTAMINATION

HO 338/141

W 1895

RELATED PAPERS

THE DECONTAMINATION OF RESIDENTIAL AREAS.

Survived 1st Review C.R. Stanbury 9/12/71

DESTINATION	DATE	Initials	DESTINATION	DATE	Initials	DESTINATION	DATE	Initials
Dr. McAulay	25.11.59	J.B.						
Mr Leader-Williams	2.12.59	J.B.						
Mr Stanbury	3.12.59	J.B.						
Dr McAulay	4/12/59	[illegible]						
Dr. Purcell	5.10.60	J.B.						
SAB Registry	8/10/60	[illegible]						
Dr Purcell	14/11/60	[illegible]						
Dr Purcell	7.4.61	JSS						

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5.

THE QUEEN'S UNIVERSITY OF BELFAST

DEPARTMENT OF PHYSICS

TELEPHONE: BELFAST 30111

SAN 12/8/1

30th November, 1959.

Dr J. McAuley,
Scientific Advisers Branch,
Home Office,
Whitehall,
London, S.W.1.

Dear Dr McAuley,

I have read through the paper CD/SA 96 (restricted), and really cannot criticise it at all.

Yours sincerely,

K G Emeleus

K. G. Emeleus

MINUTES

(Additional Minute-sheets should be filed on this side)

Doc 1 The Decontamination of Residential Areas CD/SA 96

I want to get this over to Porton and the Ministry of Supply S.A.C. as soon as possible. Porton have already started negotiating a large scale trial with Joint School of Nuclear Defence. I have left the U.S. data untouched as each lot has its own background. For Decontamination Study as a CD/SA perhaps we ought to boil the appendices down a bit. I should be happy to take the Camp Stoneman data B(iii) set and Plumbob B(ii) for this purpose. May I have your comments please.

Intd. J. McA.
9/10/59.

Mr. Leader-Williams
Dr. Purcell

I like this paper and I think we should send several copies to the D.G. with a cover note suggesting that the time has now come [illegible] of Decontamination organisation; that clearly the Fire Service and Local Authority sanitary departments are involved and that it is for consideration [illegible]

Dr. Purcell.

Intd E.L.W.
14/10/59.

I also like it. See few comments on pages 3,6,8. The possible value of earth barriers Appendix B(ii) deserves further study, is it worth putting in a few more words on this? Proceed with reproduction and distribution as proposed.

Intd. [illegible]
1[illegible]/10/59

Dr. McAulay

A copy has been sent to Green (C.D.E.E.) and one to the Secretary of the S.A.C. Committee. See file SAG 10/39/1 59 Also report his being duplicated as a CD/SA (90 copies, for D.G. and H.H., Radiological Group, S.R.T.D., Scientific Advisers.

Intd. J. McA.
15/10/59.

Doc.2. CD/SA 96 Final Version

Doc.3. Dr. Purcell sends copies of CD/SA 96 to the D.G. & comments on decontamination in general. 6.1.59

Doc. 4. Mr Jackson comments on CD/SA 96.

Dr. McAulay. 25.11.59.

Doc. 5. Prof. Emeleus acknowledges receipt of CD/SA96.

Doc. 6. Note by the D.G. on action to be taken re decontamination
Dr. Purcell RHP. 30.11.59
Mr Leader Williams [illegible]
Mr Stanbury [illegible]
Dr. McAulay. JMVA 11/12

Three copies of Dr. McAulay's paper on order for
D.G. H.M. 2/12/59. 3 copies sent to D.G. 15/12/59
G. Pepper 15/12/59

Doc. 7. Dr. Woods would like to make decontamination paper cover wider scope than at present

Dr McAulay I spoke to Woods on 11.12.59
phone — only decontam of residential areas wanted in discussion. He wants summary for the SAC I suggested James 1-9. JMVA 11.12

Doc 8. Note of discussion with C.D.E.E. reps. on the decontamination programme 14.3.60

Doc. 9. Col. Noel sends notes on decontamination
24.5.60

Dr. McAulay.

Doc. 10. CD/SA96 Addendum Application of U.S. performance data to a London District.

Doc. 11. Dr. Norton sends comments on CD/SA 96
5.10.60.

Dr. Purcell RHP.

Doc. 12. Dr. Purcell replies to doc. 11. 7.10.60.

NOTE: this report follows from the "Report of a course given to university physics lecturers at the Civil Defence Staff College 8-11 July 1957" (UK National Archives doc. HO 228/21) which contains papers by Frank H. Pavry on blast data including height of burst effect curves, A. G. McDonald on the contribution of scattered thermal radiation (depending on the field of view of the sky), etc.

~~CONFIDENTIAL~~ A12/Z23

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DOWNGRADED TO Unclassified
Authority SAG 79 3/3/1
Date 7-1-81 Initials

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SCIENTIFIC ADVISERS' BRANCH

REPORT OF A CONFERENCE OF THE REGIONAL SCIENTIFIC ADVISERS FOR CIVIL DEFENCE, HELD AT THE CIVIL DEFENCE STAFF COLLEGE, SUNNINGDALE PARK, 12th to 14th MAY, 1959.

October, 1959.

~~CONFIDENTIAL~~

Report of a Conference of the Regional Scientific Advisers for Civil Defence, held at the Civil Defence Staff College, Sunningdale Park, 12th to 14th May, 1959.

The Conference was attended by Regional Scientific Advisers in England and Wales and Northern Ireland, by Regional Directors of Civil Defence and Officers of a number of Departments. The following were present for the whole or part of the proceedings:-

Scientific Advisers

Professor G. E. Coates, M.A., D.Sc., F.R.I.C.	Northern Region
Professor W. Bradley, D.Sc., Ph.D., F.R.I.C.	North Eastern Region
Professor L. F. Bates, Ph.D., D.Sc., F.R.S.	North Midland Region
Professor D. D. Eley, M.Sc., Ph.D., Sc.D.	" " "
Professor L. Hunter, D.Sc., Ph.D., F.R.I.C.	" " "
B. C. Saunders, Esq., M.A., Sc.D., D.Sc.	Eastern Region
Sir Charles Ellis, B.A., Ph.D., F.R.S.	London Region
Emlyn Williams, Esq., B.Sc., Ph.D., F.R.I.C.	" "
G. E. Watts, Esq., M.A., Ph.D., B.Sc., F.R.I.C.	South Eastern Region
N. Pentland, Esq., M.Sc., Ph.D., F.Inst.P.	" " "
E. G. Cowley, Esq., M.Sc., Ph.D., F.R.I.C.	" " "
H. W. Thompson, Esq., C.B.E., M.A., D.Sc., F.R.S.	Southern Region
Professor W. E. Garner, C.B.E., D.Sc., F.R.S.	South Western Region
Professor F. C. Frank, O.B.E., D.Phil., F.R.S.	" " "
J. W. Cook, Esq., D.Sc., Ph.D., Sc.D., F.R.S.	" " "
Professor G. K. Conn, M.A., Ph.D.	" " "
Professor F. Llewellyn Jones, M.A., D.Phil., D.Sc.	Wales
S. T. Bowden, Esq., D.Sc., F.R.I.C.	"
Professor M. Stacey, D.Sc., Ph.D., F.R.S.	Midland Region
Professor P. B. Moon, M.A., Ph.D., F.R.S.	" "
Professor J. R. Squire, M.A., M.D., F.R.C.P.	" "
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PROGRAMME OF THE CONFERENCE

Tuesday, 12th May

	Conference Assembles	
20.30	Introduction by the Under Secretary of State	Sir Charles Cunningham
	Science and Defence, past, present and future	Sir O. Wansbrough-Jones

Wednesday, 13th May

09.30	Welcome by the Commandant	Major General F. R. G. Matthews
09.35	Opening Address by the Chief Scientific Adviser	Dr. R. H. Purcell
09.45-11.00	Working Party on the Operation of Scientific Teams at Region and Below.	
	(i) Introduction of the First Report on operations at Regional level.	Dr. R. H. Purcell
	(ii) Discussion of the Report by Regional Scientific Advisers and Regional Directors.	
11.00-11.20	COFFEE	
11.20-12.20	Part III Training of Scientific Intelligence Officers	
	(i) Regional Courses and Exercises based on the Easingwold Course.	Mr. T. Martin
	(ii) Local Authority Exercises, Exercise "Arc".	Mr. E. Leader-Williams
12.20-12.45	Summing up of the morning's proceedings by the Director General	General Sir Sidney Kirkman
	LUNCH	
14.15-14.35	Radiation Tolerance Doses in Civil Defence. Position reached since the last Conference	Mr. G. R. Stanbury
14.35-15.15	Deployment of Civil Defence Forces in relation to Radio-activity.	Mr. E. Leader-Williams
15.15-15.45	The Operational Implications of Serial 8	Mr. K. P. Witney
15.45-16.15	TEA	

Wednesday, 13th May (contd.)

16.15- 17.10	Study "Pikadon". Presentation of the position at Sub-Region at H + 2 and H + 4 following a ½ M.T. bomb on Newcastle.	Staff College
17.10- 17.45	Discussion of Serials 7 - 10.	Mr. G. R. Stanbury to open

Thursday, 14th May

Scientific aspects of the Problem of living in an area contaminated by Radio-active Fall-Out.

09.30- 10.00	(i) Survey of Protection against Fall-Out afforded by Houses and other buildings.	Mr. D. T. Jones
10.00- 10.30	(ii) Radio-active Decontamination.	Dr. J. McAulay
10.30- 11.00	(iii) Discussion on Serials 12 and 13.	
11.00-11.30	COFFEE	
11.30- 12.15	(iv) Food and Agriculture	Mr. G. Wortley
12.15- 12.45	(v) Food Monitoring	Brigadier J. A. Mullington
	LUNCH	
14.15- 15.00	(vi) Discussion on Serials 15 and 16.	
15.00- 15.45	Fire Problems after a Megaton Explosion Study "Torquemada".	Mr. G. R. Stanbury
15.45- 16.00	Conclusion	
16.00	TEA. Conference disperses.	

MR. LEADER-WILLIAMS: We certainly may be, but a limit would soon be reached because of the time taken in giving first aid and in delivery to the ambulances.

DR. PURCELL: I would have thought that Professor Squire was absolutely right in saying that we must make more use of private motor cars to carry the injured.

DR. MURRAY: I imagine the figures quoted do not include private cars; possibly they could be used.

MR. WITNEY: We were working on that basis. The station-wagon type of car could certainly be used, and ordinary cars could be used for sitting cases.

Thursday, 14th May.

XIV MR. JONES described a Survey of the Protection against Fall-out afforded by Houses and Other Buildings. He said:

This work was begun in 1956 when the White Paper on Civil Defence (Cd 9691) called for a sample survey to be made to find the level of protection against fallout which houses and other buildings could provide. The survey of private houses was started in 1957 and has now been completed. You will have had a paper describing the results of that survey - CD/SA 89.

Private Houses. The Home Office obtained the co-operation of the Local Authorities in eleven urban and rural districts which were considered to represent typical reception areas in the country. None of the large conurbations was included: the populations in all cases were less than 100,000, in most cases considerably less. The districts were:

Carlisle, Chesterfield, Exeter, Harrogate, Kirkcaldy, Perth, Wellingborough, Wrexham, Chelmsford, Witney and St. Boswells.

The Authorities were provided with a table which gave the protective factors of typical houses. Their task was to take a census of houses of various types and render a return of the number of households having given protective factors. On the whole the results showed that factors were lower than expected. The table on page 5 of CD/SA 89 shows that many households would have factors less than 40.

The Authorities were asked to consider three possible schemes of protection. Under Scheme A householders would stay in their own dwellings; under Scheme B they could move, if they occupied part of a building such as a flat, into the best part of the building; and under Scheme C they would make use of an underfloor trench in their own premises - if this were feasible.

Some of the outstanding results showed that in rural districts 45% had factors less than 25, 40% less than 40, and 97% less than 100. For rural districts under Scheme C, the corresponding percentages were 35%, 57% and 76%. In urban districts the corresponding precentages were 31%, 57% and 90% under Scheme A, and 11%, 40% and 52% under Scheme C. Combining rural and urban districts with appropriate weighting we found 'natural' estimates under Scheme A to be 36%, 64% and 95%; and under Scheme C to be 21%, 46% and 61%. There was some improvement in rural and urban districts in Scheme B and Scheme A, but on the whole this was very slight.

In some areas it was found that the factors at the centres of towns were distinctly higher than at the outskirts. In Chesterfield, for example, there was a marked difference, but in Kirkcaldy there was not much difference.

Communal Buildings. The Survey of communal buildings, that is buildings other than private houses which could be used as shelters, was begun in November last year. There were buildings such as theatres, churches, schools, office blocks, department stores and so on, which could accommodate large numbers of people. This work is not complete, but some interesting results have already been received.

XV DR. McAULAY gave a review of progress in Radioactive Decontamination. He said:

It is three years since we last reviewed the problems of radiological decontamination. Of the few papers which have come in the first is one from the Chemical Defence Experimental Establishment - PTP (R) 20, which gives an account of their experiments on Decontamination of Skin and Clothing. There are two American papers that you might like to study at your leisure. One of them is a paper by the staff of the Stanford Research Institute under contract to the Office of Civil and Defense Mobilisation - CD 11727 - entitled 'Systems Analysis of Radiological Defence'. The other one is a report on 'Operation Plumbbob' - American Atomic Energy Commission - CD 11605. There are two other papers that I want to refer to - one is the very voluminous report on The Radiological Recovery of Fixed Military Installations, which seems to be based on questionably high effectiveness in cleaning up surfaces. The chart shows the residual number, i.e. the activity remaining after decontamination. We are rather doubtful about all these figures and particularly about 95% clean up of a concrete road by fire-hosing. The other report is by Technical Operations Incorporated - Radiological Defence Planning Guide. This particular group was asked to produce a complete defence plan for O.C.D.M., but their work is based on the same data which appear to relate entirely to large particles from bursts on desert sand, and easy to remove by simply blowing or washing them away.

Coming to the problem of the removal of contamination from skin, clothing, vehicles or equipment, this is a secondary problem because it is difficult to imagine conditions where the radioactive dust hazard could be serious without simultaneous lethal gamma exposure. In spite of high standards of personal cleanliness you may later get a Beta burn, but it is still only a burn. The main object of decontamination of skin and clothing is to keep the Operating Theatre clean and to keep contamination from getting into wounds or into food and drink. The first problem that Porton faced was to get a suitable simulant for fall-out. They produced a simulant consisting of glass microspheres impregnated with 0.15% Ta and these were irradiated in a pile to roughly .1 mc/gm. The microspheres were 10 to 100 microns in size which is the biggest they can make. The 10 micron particle represents something much more difficult to remove from skin and clothing than the kind of particle Mr. Stanbury was talking about, i.e. fall-out particles of 75 microns and above.

Then they had the problem of getting live skin, which was difficult, so they made a skin replica by taking an epoxy resin cast and from this they obtained a positive using a solution of methyl nylon in chloroform and alcohol. The replica gave a good representation of the mechanical surface of human skin. Porton found that with particles of 10 to 100 microns, by using ordinary soap and water, they could get effectively over 98% removal. In the case of clothing contaminated with these glass microspheres they found brushing or shaking ones jacket is not a very effective way of removing these particles - less than 60% in some cases - so they tried washing with detergents. I cannot imagine anyone doing this with a suit, but with washable fabrics over 98% was removed in this way. The fabrics were placed in the tub or in a washing machine and stirred about 100 times. In the case of outer clothing they naturally felt this was not desirable so they tried vacuum cleaning and got more than 98% removal.

Before going on to the question of decontamination of areas, there is one very important piece of real factual evidence I wish to mention. If a particle say of earth - 200 microns - is sucked up into the cloud, and fission products condense on it, and if that particle gets wet coming down, the activity after about 10 minutes becomes, to a large extent, fixed in the particle. Also, if the particle comes down on to a wet surface, and is wet for 10 minutes, the amount of transfer is likely to be negligible. Except for water bursts our problem is going to be very largely a mechanical one of removing the particles from the contaminated surface.

Now area decontamination. Here we are faced with the problem of a heavily contaminated built-up area, and what to do after 48 hours. We have to decide for instance, whether it is going to be worth while to clean up

roads, pavements, roofs etc. and when we ought to do the jobs. We have not got very clear answers to this problem in spite of the voluminous reports from America. The experimental work in the U.K. is being done by Porton who have recently acquired a road sweeper and various other items of equipment needed to clean up an area. They will carry out trials as soon as supplies of suitable simulant are available.

Let me go back to two years ago. Many of you probably read the Report of the Physics Lecturers Course. There I reviewed the problem and the many factors involved on which we have no accurate data. A number of factors were combined into one Parameter:-

$$N = \frac{PX\ T_{(25)}}{2L}$$

where P is the resident population, X in feet per hour is the rate of clean up of a street, L the total street length to be cleaned, and $T_{(25)}$ the time in hours the operators could work before getting a dose of 25r. N represents the number of residents per operator required for decontamination. Thus if decontamination were started at 2, 4 or 6 days after the burst, the values of N would range from 185 to 370, from 500 to 900, and from 800 to 1,500. Now I assumed in doing the decontaminating that people came from outside to operate the road-sweeping equipment. Just before that, one person in each house came out for not more than half an hour and brushed all the contamination from the pavement and sidepaths into the street gutter. Following on the road sweepers which swept the fall-out into the street gutters, a water tank and pump enabled the contamination to be washed along the gutter and down the drain. It is interesting to note that in one of the American Operational Research reports the range of effort covered is one operator per 100 of the population up to one per thousand. The U.S. report - Radiological Recovery of Fixed Military Installations - gives some figures about rates of cleaning up. They assumed motorised flushing equipment, graders which scrape the earth into a windrow pile and leave it at the side, scrapers which lift up this windrow and put it into a container so that it can be moved and dumped somewhere else. They used bull-dozers, ploughs, and so on. They give the rate for fire hosing a street as 6,000 gallons per hour at 80 p.s.i. through each of two $1\frac{1}{2}$ inch hoses and four men to each hose, or 7,500 sq. ft. per hour per hose. In the case of motorised equipment, i.e. the water flushing machine with two very powerful nozzles in front - this delivered 50,000 gallons per hour at 90 p.s.i. employing two men and decontaminating some 35,000 sq. ft. per hour. In the Plumb bob report the calculations were something of the same order - an unpaved area of 500 ft. X 500 ft. = 250,000 sq. ft., was decontaminated in three hours or 80,000 sq ft. clean up per hour. In my case I estimated the rate of street cleaning with a road sweeper and firehosing at between 40,000 and 150,000 sq. ft. per hour, assuming that contamination is washed down into street drains.

Now let me come to the Stanford Research Institute's study. They worked out what is called a 'methodology' for assessing the value of a decontamination procedure. Unfortunately they used a complicated basis of assessment, first a 'performance' value which is the rate of coverage multiplied by the fractional reduction of radiation divided by the exposure factor. From this they worked out a 'decontamination' value, which is the performance value multiplied by the fraction of open field radiation penetrating a shelter divided by above-ground area per capita. The results work out very much in the same range as we calculated. Two cases are assumed (a) 1 operator per 100 of the population, and (2) 1 operator per 1,000 of the population. The bulk of the effort is done by mechanised equipment but the population are expected to do a bit of spade work on unpaved areas. In the paper they give very interesting data on the distribution of certain types of surface in American towns and the proportion of certain classes of people likely to be available and useful for undertaking the decontamination. Assuming one operator per hundred of the population, a 50% dose rate reduction could be achieved if each member of the crew worked two 10-hour shifts, and a 90% dose rate reduction if each worked twenty 10-hour shifts. In my assessment I took only 25r as the limit of exposure for people engaged on decontamination. I must now go back and do it again for a wartime emergency exposure of 75r if this is justified to enable the community to survive. I might add that this particular SRI report - if anybody is interested enough to read it - has a beautiful graph. It shows the cost of saving the United States of

America in relation to the actual cost of the protective decontamination programme, in terms of the surviving population.

It is interesting to note that in an average American town, per 1,000 inhabitants there are 0.7 Sanitary Department employees, one fireman, 2.9 highway department workers, 1.4 policemen. These with watchmen and cleaners make up 1.8% of the total population possibly able and available to do this job. They have also considered that in America, of course, all cars would have their tanks at least half full in emergency - that means something like 10 hours travelling at 25 miles an hour, so everybody could beat it out of the contaminated area for some 250 miles. Each would have to take his own food, and this is where the Stanford Institute's estimate stops. They say they can carry the operation no further because they do not know what would happen when the family food supplies ran out.

I would like now to refer to the extremely valuable factual report on Operation Plumbbob in 1957. The report is called the 'Evaluation of Countermeasure System Components and Operational Procedures', but I don't think one ought to let the title frighten us away from the value of the report. They built an underground magazine type shelter about 25 ft. in the middle by 48 ft. long, covered with 3 ft. of earth, and they carried out a study of the dose rates during gamma flash and residual effects inside and outside the shelter to several days after the burst. It had large ventilators and one of the objects was to study the internal dose at various points inside in relation to the various apertures of the shelter. In the second part of the programme - three areas outside were selected as likely to receive fall-out. In one of the shots this particular shelter was almost a mile from Ground Zero. After the shot the fall-out built up over the shelter very rapidly - it started in about six minutes and it reached a maximum in 15 minutes from the burst. The maximum was 60 r.p.h., which is higher than they had budgeted for. It had been intended that a party should come out from the shelter to monitor the areas and to decontaminate one of the selected areas seven hours after the shot, but in an area at 60 r.p.h. at 15 minutes after burst, this was not possible until two days after and it presented a very valuable opportunity as the area was thoroughly monitored before and after decontamination and all personnel carried film badges. Three areas had been marked out, and at 7 hours after burst monitors were sent out to measure the dose rate at the centres of the three areas. One area which had a fairly high dose rate of 3 r.p.h. at 7 hours was selected. The area was a square of 500 ft. side. Two days after the burst four monitors went out and started at the centre and proceeded in steps to each corner, and the whole area was very thoroughly monitored at heights above the ground of 1 ft., 2 ft. and 3 ft. Another monitor went to various points outside and measured the dose rates so that we have a complete record of all relevant dose rates before, during and after the decontamination operation. The crews and their equipment consisting of four motor graders (pushing the earth to the side into windrows), two motorised scrapers, and one bull-dozer was kept three miles from G.Z. in a clear area. Decontamination was done in four stages and took three hours. In the first stage an area of 40 ft. X 40 ft. was cleared and then an additional 20 ft. round the periphery. This was then extended to 100 ft. X 100 ft. and finally to 500 ft. X 500 ft. The central area of 100 ft. X 100 ft. was monitored and rescraped in an attempt to get down to a residual number (R.N.) of 0.01, i.e. 99% dose rate reduction at the centre. However this was not achieved. The results at 3 ft. height were:-

Area	R.N. at Centre (average)
40ft. X 40ft.	0.39
60ft. X 60ft.	0.32
100ft. X 100ft.	0.24
500ft. X 500ft.	0.16

A second pass over the 100 ft. X 100 ft. area gave an R.N. of 0.11. The ground was rough and hard and a lot of boulders had to be removed which slowed them down very considerably.

wanting to go into the middle of a Z zone for the food there until considerably later, and it does look on a first analysis as though his tasks will develop in a fairly orderly way.

BRIGADIER MULLINGTON: I see him starting fairly early. The Regional Food Controller will be edging round to see where he can get food from for areas badly hit.

DR. PURCELL: Well I quite agree with that, but I am equally convinced that his movements will be limited by the public control conditions and the gradual clearance of the zones. Could I ask you to continue to turn this problem over in your minds and let me have any considered opinions that you may have by correspondence: that is the best conclusion for this afternoon.

III MR. STANBURY gave a talk on Study Torquemada, dealing with Fire Problems after a Megaton Explosion. He has provided the following summary:-

I. Estimation of initial fire incidence

The method used is based on that described in the Report of the Technical and Tactical Study Courses held at the Fire Service College in May, June and July 1952 entitled "The Fire Situation after an Atomic Attack on a British City" - a copy of which can be made available on application.

The British city concerned in these particular study courses was Birmingham and for this purpose a 1 in 12 scale model was made by the Birmingham Fire Brigade covering a 25° sector of the area likely to be affected by the explosion of a nominal atomic bomb over the centre of the city. With this model the problem of shielding - which is all important in this connection - could be dealt with quite satisfactorily. A lamp was set up at the point of burst in relation to the model, and it could be seen immediately which windows were exposed and which were shielded. After that it was only a question of estimating the chances of the development of continuing fires in relation to the fire risk and size of the fire compartment concerned by the methods described in detail in the report.

In this study we were concerned with the much larger area of damage produced by a 1 MT explosion, and we had no model. We are forced therefore to use maps and the most detailed maps available were the Insurance Plans of Liverpool and Birkenhead prepared by Messrs. C. E. Goad Ltd., which were hired specially for the purpose. These are to the scale of 40 ft. to the inch and they give complete details about road widths, height of buildings, construction etc. In order to reduce the volume and tediousness of the work involved in using maps the method developed for the Birmingham model had to be substantially simplified.

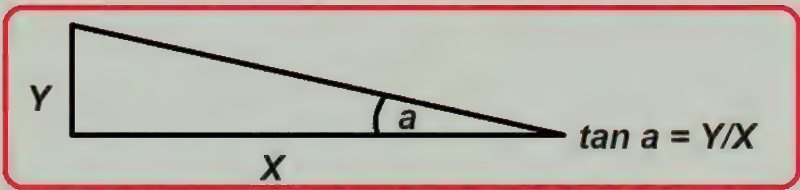
Effect of Shielding: Estimation of the Number of Exposed Floors

Assuming that buildings on opposite sides of a street which is receiving heat radiation from a direction perpendicular to its length are of the same height, then the number of exposed floors on the front of the buildings on the side of the road away from the explosion depends on

(a) the angle of arrival of the rays, say α and

(b) the width of the street = 10w

Where w = number of units of 10 ft.



If we take the average depth of a floor to be 10 ft. then the number of exposed floors is given by

$$\tan \alpha = \frac{10n}{10w} \qquad \text{or } n = w \tan \alpha$$

For a 1 MT groundburst bomb the height of the top of the fireball above ground is about 0.72 miles. Because this distance is large compared with the height of most buildings, the exposed upper floors do actually see a large part of the fireball and not just the top of it, but in assuming that the radiation is just as intense from the top as from the middle we are probably overestimating the fire situation which will result.

On the above basis the following table gives the number of exposed upper floors (to the nearest ½ floor) for a range of distances from the explosion and a range of street widths.

Hence at 5 miles from 1 megaton ground burst, only top windows are exposed

TABLE I

Distance from explosion	Angle of arrival	$\tan\alpha$	Width of street (units of 10 ft.)						
miles	$\alpha°$		2	3	4	5	6	7	8
1	35	.72	1.5	2	3	3.5	4.5	5	6
1½	26	.48	1	1.5	2	2.5	3	3.5	4
2	20	.36	.5	1	1.5	2	2	2.5	3
3	13½	.24	.5	.5	1	1	1.5	1.5	2
4	10	.18	.5	.5	.5	1	1	1.5	1.5
5	8	.15	.5	.5	.5	.5	1	1	1
6	7	.12	-	.5	.5	.5	.5	1	1
7	6	.1	-	-	.5	.5	.5	.5	1

It is obvious that for street widths greater than 80 ft. at close ranges (or for example where there is an open space in front of a building) it can be immediately assumed that all floors are exposed; since few buildings have more than 5 or 6 floors. At the extreme range for ignition the angle of arrival varies so slowly that for street widths greater than 80 ft. the number of exposed floors can always be taken as one. It is for these reasons that the Table is stopped at 80 ft.

To the numbers obtained from Table I must be added or subtracted the differences in numbers of floors of opposing buildings as shown on the maps to give the actual number of exposed floors in any particular case. This number of course cannot be negative, nor greater than the total number of floors in the building exposed.

Variation with Range

In the Birmingham study an attempt was made to allow for the variation in intensity of the radiation, with distance from the explosion on the chance of ignition, but the foundation for this was not very sound. In this study it was assumed -

(a) that there are no continuing fires inside a circle 1 mile in radius because of the complete collapse of all buildings

(b) that out to 1½ miles the only fires possible are those in buildings of steel framed or reinforced concrete construction

(c) that the chance of ignition is 100% all the way from 1½ miles to 5 miles, after which it drops to 30% for a further 2 miles. [At 7 miles from a 1 MT explosion the heat intensity is still 12 cal/sq.cm which is sufficient to ignite easily inflammable material like "Excelsior".]

Inclination of Streets to the Direct Line of the Heat Flash

The first two lines of the following table are taken from the Report already referred to.

TABLE II

Angle between heat flash and street (degrees)	90-75	75-60	60-45	45-30	30-15	15-0
Proportion of heat flash entering windows %	99	92.5	80	60	40	14
Proposed grouping for Torquemada	100%		80%		Nil	

For working with Goad Maps, the division into 6 angular groups is too cumbersome, and it was decided to use the 3 group system shown in the last line. This means that all streets inclined at an angle greater than 60° to the direction of the flash are assumed to be at right angles to it; all those between 30° and 60° have their chances of ignition reduced by 20%; and those below 30° are neglected. A small pilot study of one area showed that this approximation was very close, while the saving in work was considerable.

The chance of a continuing fire as affected by (a) Size of Fire Compartment and (b) Number of Windows.

This was dealt with in great detail in the earlier report, but considerable simplification was needed for use with the Goad maps.

The chance of a continuing fire developing from a small source of ignition decreases with the size of the fire compartment and increases with the number of sources of ignition i.e. with the number of exposed windows, and these were dealt with separately in the Birmingham model assessment. However, the decrease with size is roughly proportional to the area and the increase - because of windows - to the length (assuming an approximately square building). The overall effect is that the chance is inversely proportional to the length of the exposed front of the building.

In this study the chance has been still further reduced by two assumptions

(a) that 25% of the windows have been whitewashed and

(b) that 25% of the incipient fires are extinguished by fire guards giving an overall reduction of the chance of fire of 55% (75% x 75%).

Owing to the uncertainly connected with this part of the estimation there seemed to be no point in using more than 3 main fire compartment size groups and the figures finally adopted were as follows:-

Group (A)	20 ft. frontage.	Chance	0.2
Group (B)	40 ft. "	"	0.1
Group (C)	80 ft. "	"	0.05

In the streets inclined between 60° to 30° to the heat flash, these chances were reduced by 20% to

Group (A)	0.16
Group (B)	0.08
Group (C)	0.04

The Method of Estimation

The following routine method was adopted for making use of the principles enumerated above.

1. For any particular sheet of the Goad maps, the distance of the centre of the street to ground zero was first estimated to the nearest mile.

2. From the N/S pointer on the sheet, the direction of the flash was determined and the streets perpendicular to this (within 30°) were noted.

3. Starting from one end of each street, each exposed fire compartment was considered in turn and the number of exposed floors marked on a tracing paper overlay, using Table I together with the information on the numbers of floors of opposite buildings given on the map.

4. All the fire compartments in Group (A) were then noted and the number of exposed floors for each was multiplied by the chance of a continuing fire developing (0.2 in this case) and the number recorded on the overlay in Green. The fire compartments in Group (B) were dealt with in a similar way and the number recorded on the overlay in Yellow. Finally the fire compartments in Group (C) were dealt with, and the chances recorded on the overlay in Red.

5. This process was repeated for the buildings in the streets inclined between 60° to 30° to the flash, but using the appropriately reduced chance figures.

6. All the figures in each of the colour groups were then added to give the total chance that continuing fires would be started on any one floor of any one building for each group of fire compartment sizes. Let us assume that these numbers are x, y and z. Then these numbers of fires were marked in on the overlay as red ticks, the actual choice of which building in each group being immaterial.

Inevitably there were many classes of buildings which did not respond readily to the above method of analysis, and each had to be considered on its merits, bringing into play as much wartime experience in this field as was available to the Branch.

Secondary fires

The problem of so-called "secondary" fires i.e. - those started as a result of disruption of some kind or another caused by the blast - was dealt with in great detail in a paper entitled "The Fire Risk from Blast Damage" which also appeared in the Fire Service College Report already referred to. This was based on a careful study of all the fly bomb records. It was found that about 6% of the bombs were responsible for large continuing fires and about 40% for small fires in debris most of which went out of their own accord. If we assume that one tenth of the small fires continue the overall figure for continuing fires is 10%. In a groundburst 20 KT bomb, the damage produced is equivalent to that of about 1,250 fly bombs. For a 1 MT groundburst the number would be -

$$1{,}250 \left(\frac{10^3}{20}\right)^{2/3} = 50{,}000$$

and if 10% of these cause fires, there will be 5,000 secondary fires.

It is not expected that this type of fire would occur beyond six miles since this is the limit of damage. Thus secondary fires might occur on the average at a ~~desnity~~ density of $\frac{5000}{\pi 6^2}$ = 40/sq. mile.

Each Goad Map covers an area of approximately 1/40th sq. mile so that on each map one extra fire must be included. Here again it is not important where fire is located, but it is reasonable to select a high fire risk occupancy such as paint ~~sotre~~ store, a furniture factory, or a garage.

II. Estimation of Fire Spread

In the area of Liverpool and Birkenhead covered by the Goad Maps, the numbers of fires at H + 1 turned out to be as follows:-

Fire Compartment Size	Number
Small	1050
Medium	223
Large	20
	1293
Secondary fires allocated in roughly the same proportion	180
	1473

The area not covered by the Goad Maps was largely residential so that most of these additional fires were in the small compartment category.

The total number of fires was between 7,000 and 8,000, and it was decided to allocate the following round numbers to each category:-

Small (S)	7,000
Medium (M)	500
Large (L)	50
Total (N)	7,550

From last war experience of mass fire raids in Germany it was concluded that the overall spread factor was about 2; i.e. about twice as many buildings were destroyed by fire as were actually set alight by incendiary bombs; thus the assumptions adopted must allow for the final destruction by fire of about 15,000 buildings which is about 1 in 10 to 1 in 15 of all the buildings in the area.

For the purpose of assessing possible spread let us assume -

Proportion of fires in each category which burn out without spreading $= p_1$

Proportion of fires which spread to one other building $= p_2$

" " " " " " two " buildings $= p_3$

" " " " " " three " " $= p_4$

In each category $p_1 + p_2 + p_3 + 4 = 1$ and the final number of buildings destroyed by fire =

$$S(p_1 + 2p_2 + 3p_3 + 4p_4)s + M(p_1 + 2p_2 + 3p_3 + 4p_4)m + L(p_1 + 2p_2 + 3p_3 + 4p_4)l$$

As a first shot the following numbers are suggested:-

	Fire Compartment Size		
	Small	Medium	Large
p_1	.6	.25	.1
p_2	.2	.25	.2
p_3	.1	.25	.3
p_4	.1	.25	.4

This gives:-

Final number of buildings destroyed by fire = (7,000 x 1.7) + (500 x 2.5) + (50 x 3.0) = 13,300 which is near enough for this purpose.

In order to estimate the number of fires burning at any given time it was necessary to make further assumptions about

(a) burn-out times and

(b) starting times for first, second and third spread fires.

The following are suggested:-

	Fire Compartment Size		
	Small	Medium	Large
Burn-out time from ignition (hours)	$1\frac{3}{4}$	$3\frac{1}{2}$	7
Starting time for			
1st-spread fires	H + $1\frac{1}{2}$	H + $1\frac{1}{2}$	H + $1\frac{1}{2}$
2nd- " "	H + 3	H + 3	H + 3
3rd- " "	H + $4\frac{1}{2}$	H + $4\frac{1}{2}$	H + $4\frac{1}{2}$

These two sets of assumptions, combined with the actual numbers of fires in each category were then used to calculate the fire position at various times after H + 1 as follows:-

Time After Burst (hours)	Origination of Fire	Fire Compartment Size					
		Small		Medium		Large	
H + 1	Initial heat flash + secondary fires	7,000		500		50	
H + 2	Initial fires	Nil	2,800	500	875	50	95
	1st spread fires (p2 + p3 + p4)	2,800		375		45	
	2nd " " (p3 + p4)	Nil		Nil		Nil	
	3rd " " (p4)	Nil		Nil		Nil	
H + 4	Initial fires	Nil	1,400	Nil	625	50	130
	1st spread fires (p2 + p3 + p4)	Nil		375		45	
	2nd " " (p3 + p4)	1,400		250		35	
	3rd " " (p4)	Nil		Nil		Nil	
H + 8	Initial fires	Nil	Nil	Nil	125	Nil	100
	1st spread fires (p2 + p3 + p4)	Nil		Nil		45	
	2nd " " (p3 + p4)	Nil		Nil		35	
	3rd " " (p4)	Nil		125		20	

These numbers were divided between the various fire areas in the Liverpool-Bootle district using the H + 1 assessment as the basis. The local fire officers with their special experience of the fire risks in their areas, allocated the positions and determined where the fire spread was most likely to take place. This work, which was most painstakingly carried out resulted in the production of the four fire situation maps which you see here displayed.

XIX DR. PURCELL: I should like to say how much we have appreciated the help of the Scientific Advisers during the past year. Additionally I know that you will not wish to close without allowing me to say to the Commandant of the Staff College how much we appreciate the kindness and hospitality that we have received during this Conference. We particularly appreciate his magical touch with the weather; the sun always shines when we come here. Thank you very much indeed.

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ARMAMENT RESEARCH ESTABLISHMENT

SYMPOSIUM ON THE PHYSICAL EFFECTS OF ATOMIC WEAPONS

PAPER No. 11

Visible Radiation from an Atomic Bomb Explosion

J. Corner

AVIA 65

B.X5

1. <u>Nature of the radiating source</u>

For two or three seconds after the explosion of an air-burst atomic bomb, visible radiation is emitted from a white-hot globe, the "ball of fire", centred on the place where the bomb burst. Before dealing with the size and effective temperature of this globe we describe first how it is generated.

The shock of the nuclear explosion passes through the material of the bomb and is transmitted to the air as a very intense shock whose passage raises the air to an extremely high temperature, of the order of a million degrees K. It is this shocked air which gives the visible radiation.

As the shock passes away from the bomb, its ability to heat the air decays rapidly. Thus the outer boundary of the "ball of fire" does not continue to expand indefinitely. After a while the edge expands only because of the outward motion of the hot gases themselves. The gases are meanwhile losing energy by thermal radiation, and the recognisable ball ceases to expand after about a third of a second. The transport of energy by thermal radiation is very rapid in the earliest stages and is indeed a controlling factor in the initial motion of the boundary of the ball of fire. However, the radiation is then of the nature of soft X-rays and is rapidly absorbed. For an observer at a few hundred yards the observable phenomena can be described quite well as an expanding and cooling ball, radiating as a black body.

After a few seconds the ball ceases to be visible to the eye and the hot and buoyant gases rise, sucking in cold air as they go, to form the so-called "smoke cloud".

When a bomb is exploded underwater at depths of order 100 feet, the bubble formed is still hot enough to radiate as it breaks through the surface. The radiation is of course much weaker in this case and is a trivial hazard compared with the radioactivity.

2. <u>Radius and temperature of the ball of fire</u>

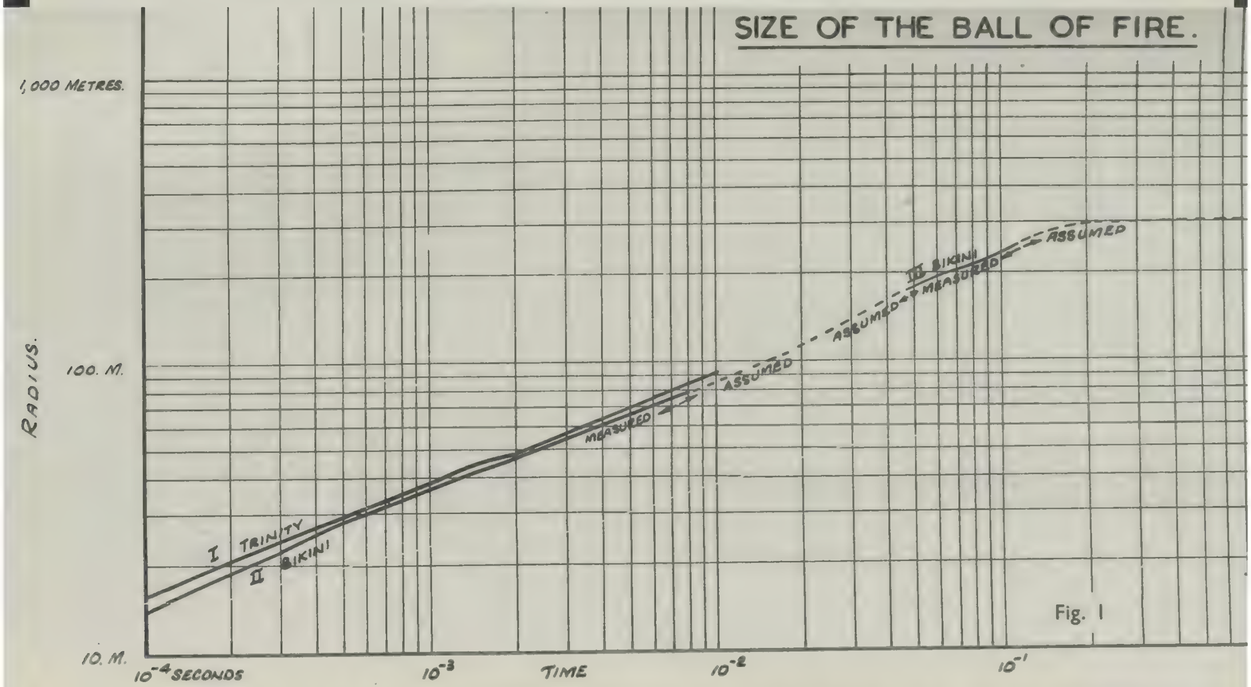

Fig. 1

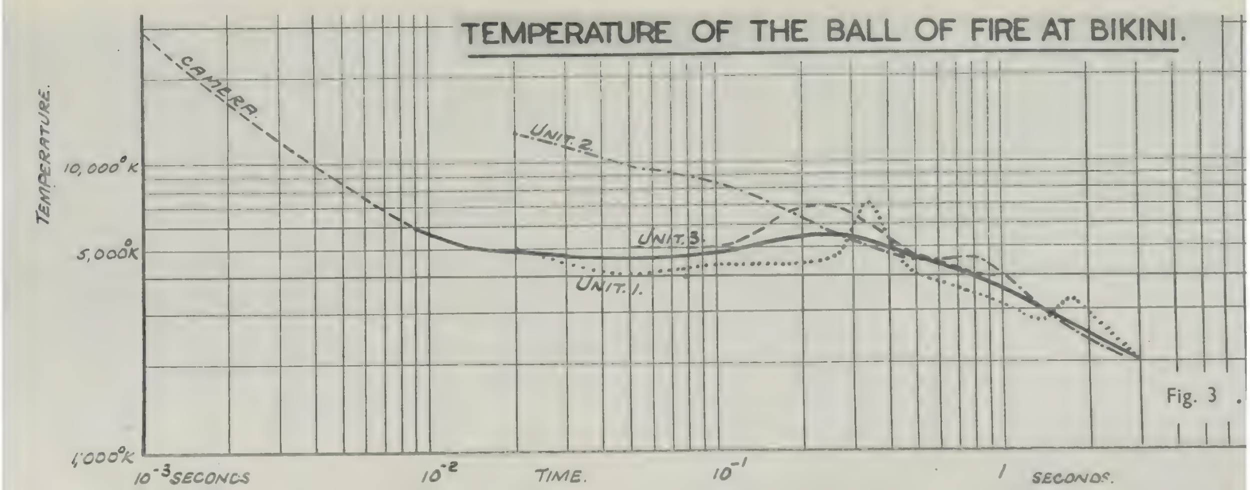

Fig. 3

We conclude that the radiation temperature falls rapidly in the first 10 milliseconds, with a main phase of almost constant temperature lasting for almost a second. The temperature then decays steadily.

3. Energy radiated

The temperature of the radiator is, for the greater part of the time, about the same as that of the outer layers of the sun. The ultra-violet light at less than 3000°A will be strongly absorbed in the atmosphere, and if we omit this we get an estimate for the total amount of effective energy radiated. In this way Mr. Woodcock has found 8×10^{12} calories, or, if we define a kiloton of T.N.T. as 10^{12} calories, the radiated energy is 8 kilotons. This is divided almost equally between visible radiation and infra-red. 8 kilotons is about 40 per cent of the energy released in the original nuclear explosion.

Fig. 4, taken from a report by Mr. Woodcock, shows his best estimate of the outward flux of energy, in wavelengths greater than 5000 A, as a function of time from explosion.

4. Ignition by radiation

Several workers have attempted to calculate the conditions under which wood or curtains could be ignited by the radiation alone. These methods agree with observations in Japan and at Bikini in showing that scorching is possible at distances of order two miles, depending on the specific heat of the material and its reflection coefficient. The blast would usually be more important as a cause of indirect fires. This view is supported also by experiments with wooden specimens exposed to the Trinity bomb.

5. Flash-burn

In practice the most important effect of the radiation is the "flash-burn" produced on human skin exposed to the radiation. As we have seen, the time-scale of the phenomenon is of order two to three seconds, so the involuntary closing of the eyes protects them from especially serious results. Dr. Pochin will describe radii for flash-burn of various degrees. Here it will suffice to mention that the effects extend to greater distances than do those produced by the gamma rays and neutrons. Fortunately even the lightest of screening is a complete protection against burns.

6. Rain and fog.

In a clear atmosphere the radiation travels away in straight lines without much absorption. If we now add rain or water-drops the radiation is scattered again and again, often ending up by being absorbed in the ground or returning to the ball of fire. In the latter case the radiation reappears later, since radiation is the main mechanism by which the ball cools. Scattering therefore increases the length of path of the radiation and so enhances the effect of any absorbing agents present, and if there are smoke particles present among the water, as in a town fog, the attenuation of the thermal radiation is very great. Of course the smoke particles now become hot and emit radiant energy, but as their temperature is lower than that of the ball of fire much of the energy is trapped in the infra-red absorption bands of the water vapour, present at saturation pressure in fog or rain. Thus mist and especially a smoky fog will cut down the risk of flashburn.

An attempt has been made to estimate the effect of smoke and fog on the radius to which flashburn is experienced. An essential feature is the transfer of energy by the smoke particles into wavelengths at which it is strongly absorbed by the water vapour present; this feature requires for its mathematical description an absorption coefficient varying strongly

[as a function of wavelength].

T 62/57

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

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REPORT No. T 62/57

OPERATION BUFFALO

Air and Ground Shock Measurements Group

Group Leader - N. S. Thumpston

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~~GUARD~~

A.W.R.E.,
Aldermaston, Berks.

November, 1957

AWRE 1956 Height of burst curves

Winifred E. Worsfold: "The Variation of Pressure on the Ground with Height of Burst, Series II. Part I: The Variation of Peak Pressure". AWRE Report No. 0-42/57

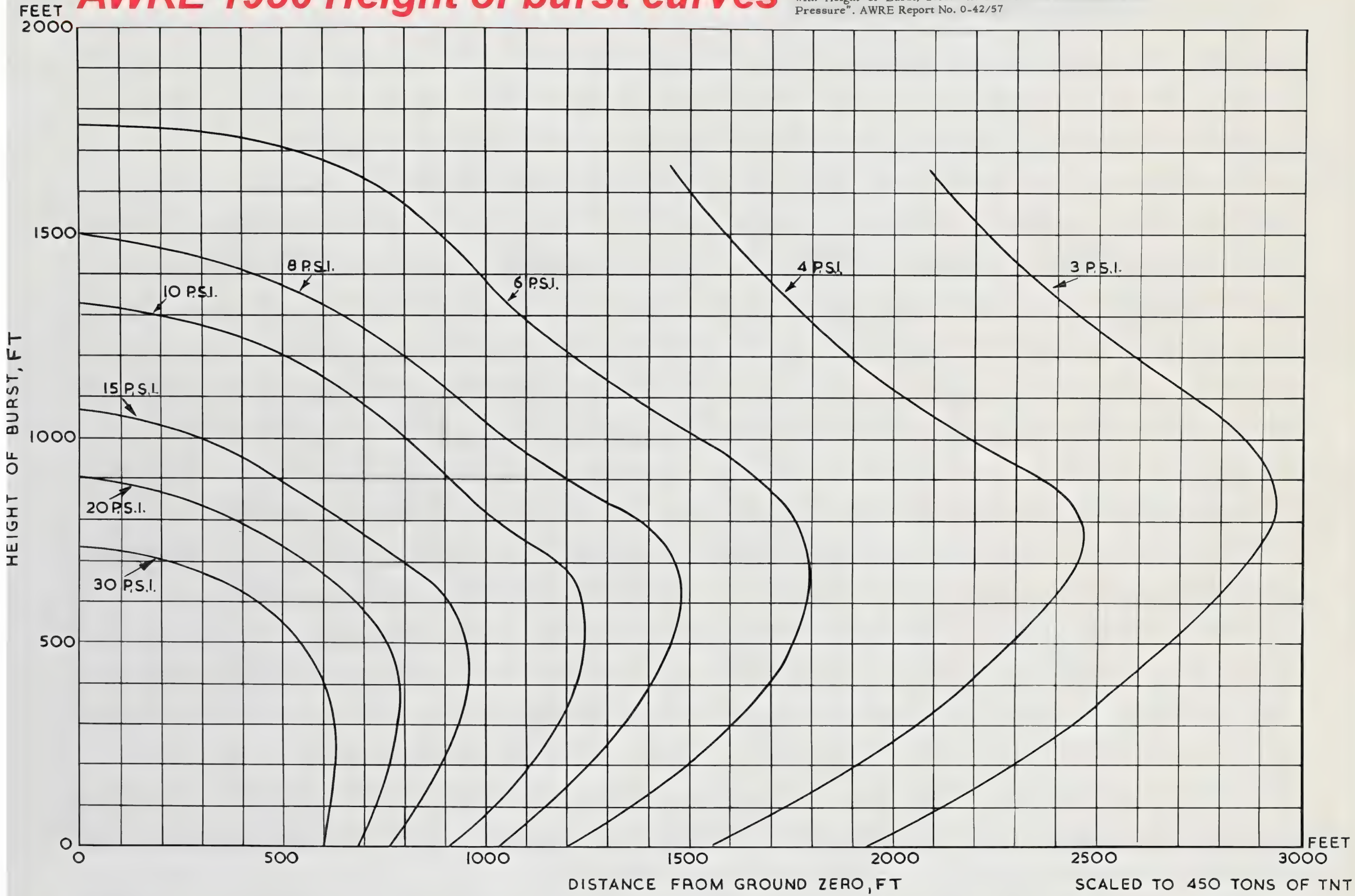


FIGURE 41. HEIGHT OF BURST: PRESSURE / DISTANCE DATA FOR 450 TONS OF T.N.T.

AWRE T 62/57 used this 0.45 kt of TNT overpressure height of burst (0.45 kt was supposed to be the blast yield of 1 kt total yield nuclear bomb) to estimate yields of 17, 1, 2.5 and 15 kt for Buffalo shots (or "rounds") 1, 2, 3 and 4.

There are issues with this, first blast yield is not always 45%, and TNT tests in the UK over concrete don't compare well to Maralinga.

15 kt at 100 ft height of burst

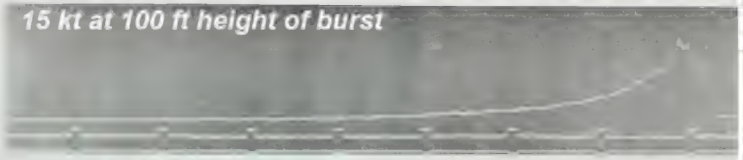


FIG.5. Buffalo-1 precursor AG 104 1170 FT. 36 P.S.I.

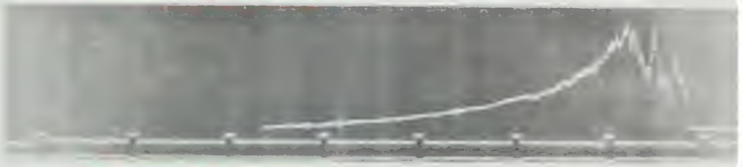


FIG.7. Buffalo-1 precursor AG 108 1520 FT. 22·7 P.S.I.

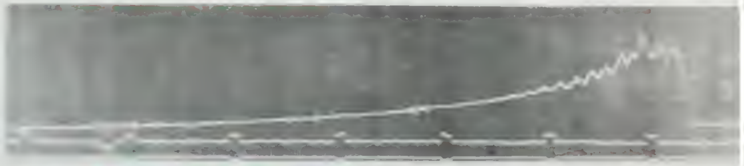


FIG.8. Buffalo-1 precursor AG 109 1730 FT. 20·4 P.S.I.

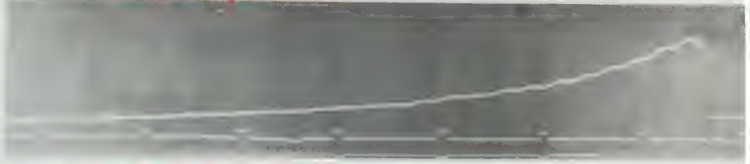


FIG.9 Buffalo-1 near ideal AG 111 1960 FT. 15 P.S.I.

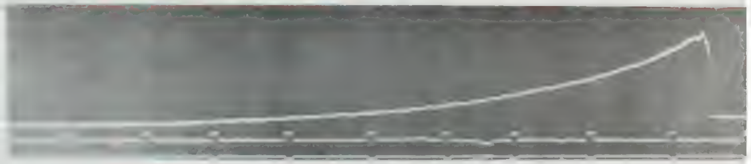


FIG.10. Buffalo-1 near ideal AG 112 2140 FT. 13·5 P.S.I.

Buffalo-1 precursor waveform development and fading
Ambient air: 22C, 998mb, 18% humidity

3 kt at 490 ft height of burst

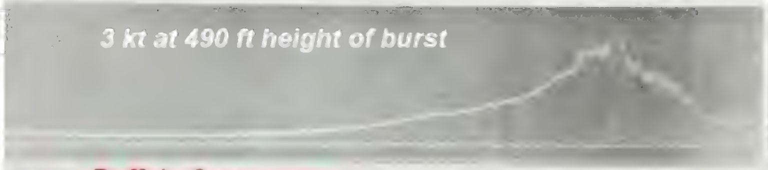


FIG.21. Buffalo-3 precursor AG 405/1 740 FT. 24·7 P.S.I.

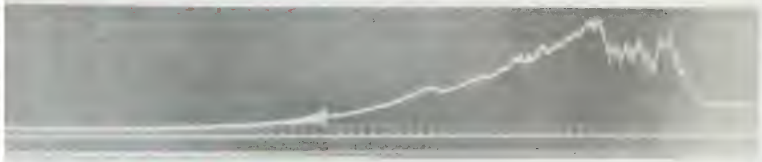


FIG 22 Buffalo-3 precursor AG 407 990 FT. 16·4 P.S.I.

FIG.23. Buffalo-3 precursor AG 408 1320 FT. 9·9 P.S.I.

FIG.24. Buffalo-3 near ideal AG 411 1750 FT. 8·9 P.S.I.

(Buffalo-3 ambient air: 24.1C, 998mb, 35% humidity)

F.M.T. blast pressure gage
with magnetic tape system

10 kt at 100 ft height of burst

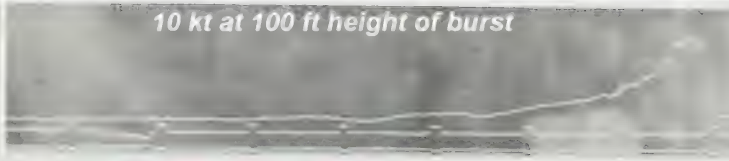


FIG 11 Buffalo-4 precursor AG 304 1140 FT 32 P.S.I.

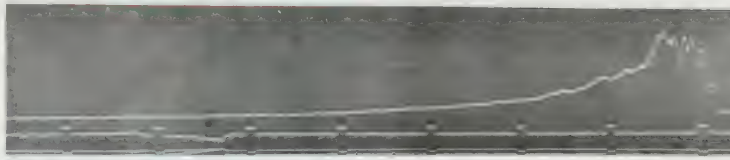


FIG 12 Buffalo-4 precursor AG 306 1290 FT. 28 P.S.I.

FIG.13. Buffalo-4 precursor AG 308 1480 FT 24·4 P.S.I.

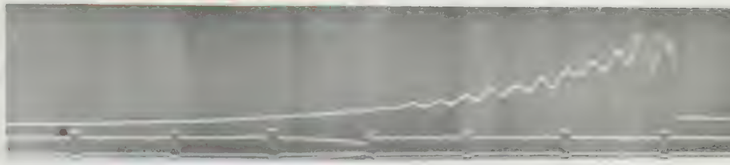


FIG.14. Buffalo-4 precursor AG 310 1680 FT. 17·8 P.S.I.

FIG.15. Buffalo-4 near ideal AG 311 1920 FT. 14·2 P.S.I.

Buffalo-4 ambient air: 13.1C, 994mb, 84% humidity

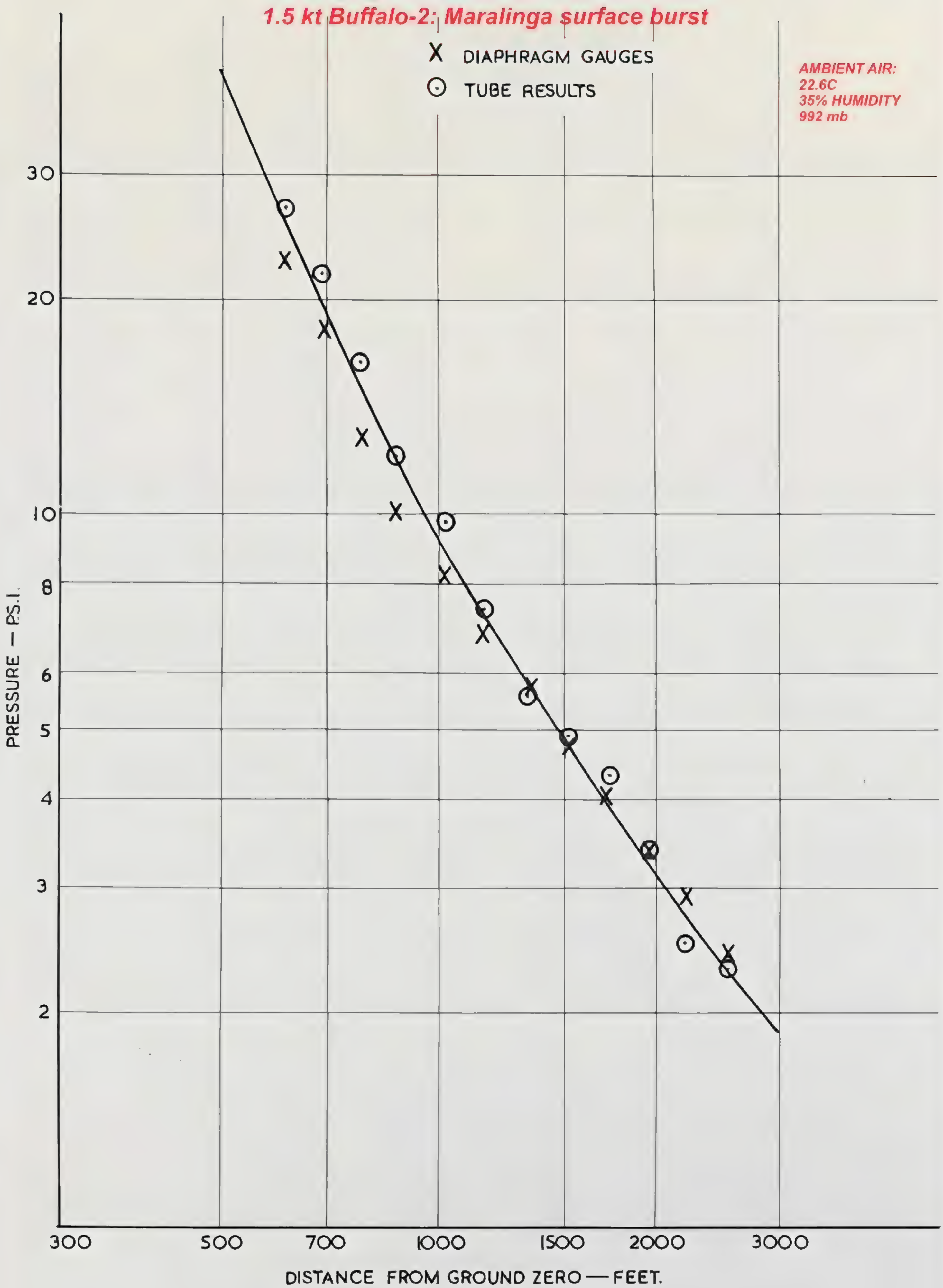
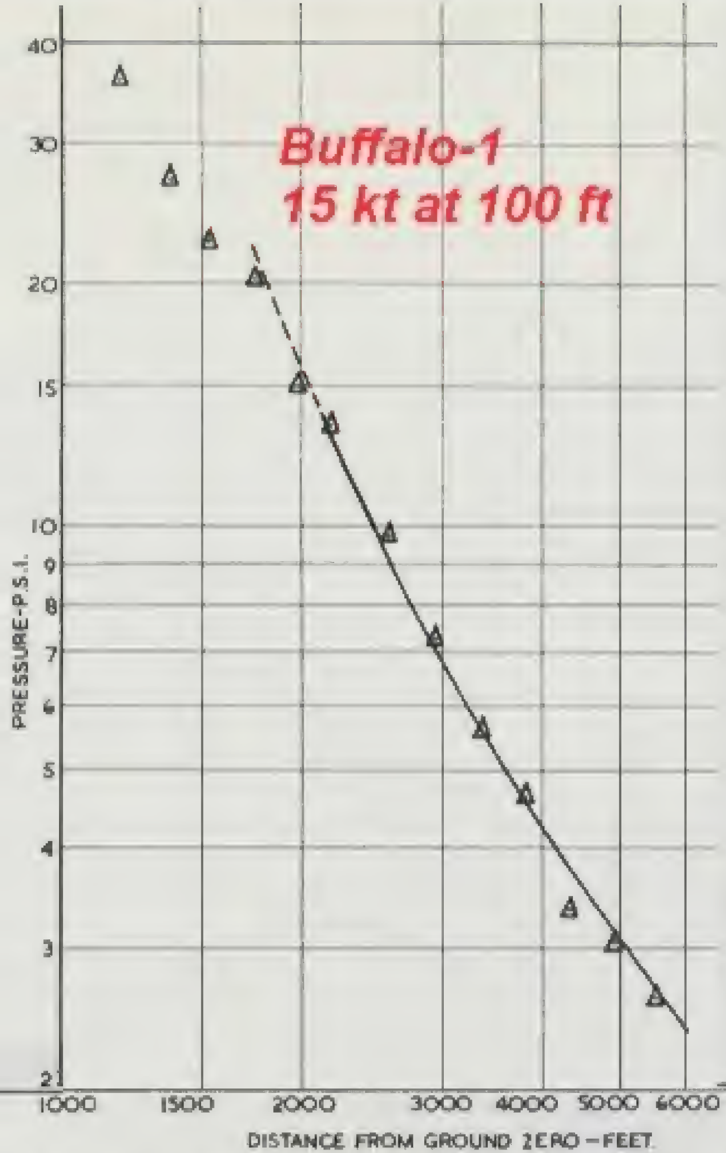
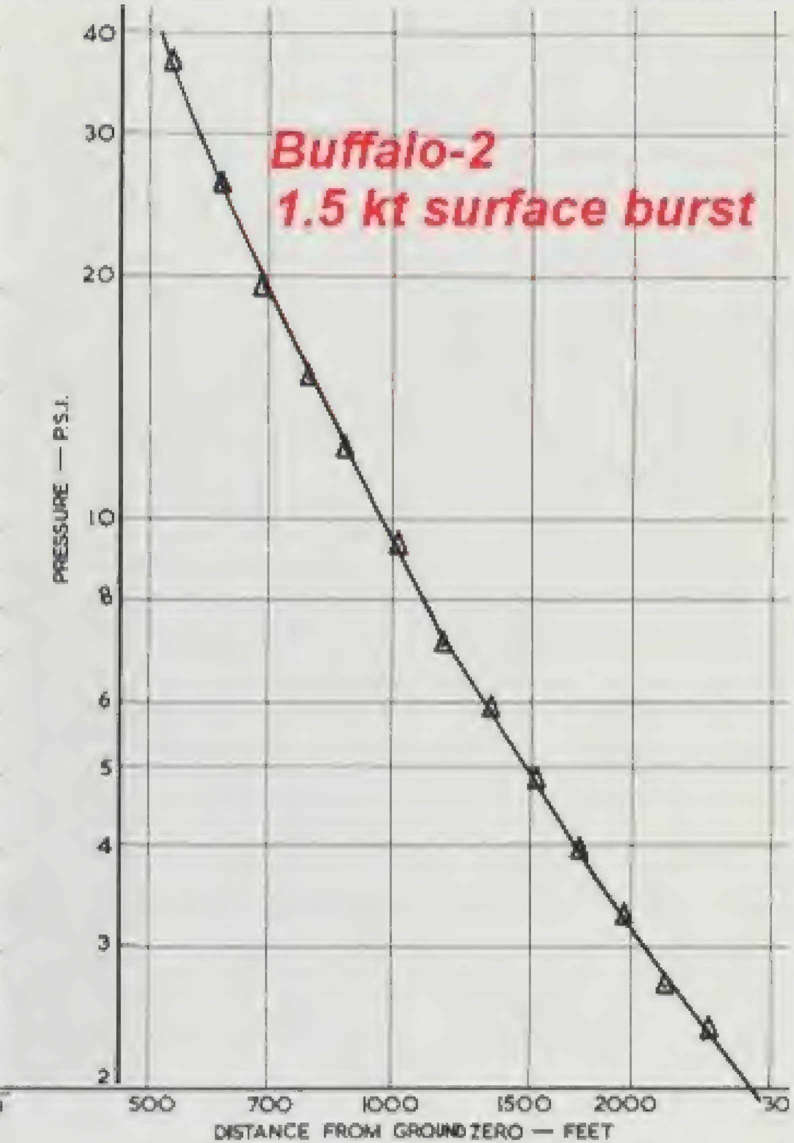


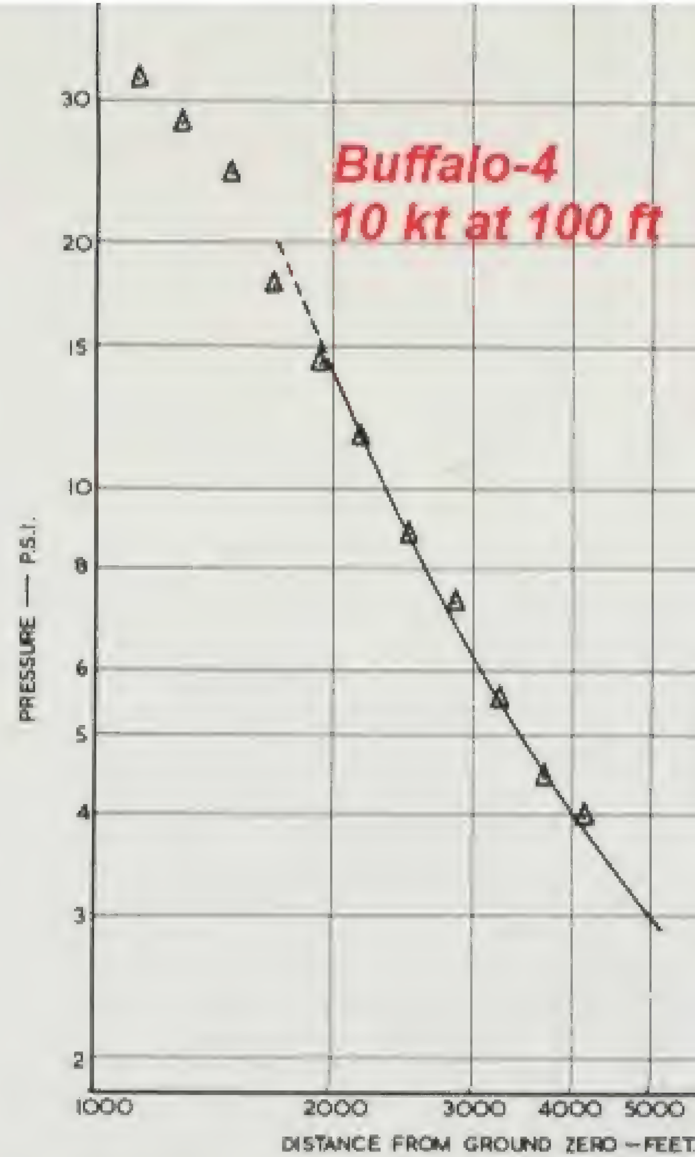
FIG. 30. ROUND 2. — PRESSURE / DISTANCE CURVE. DIAPHRAGM & TUBE RESULTS



ROUND.1. – PRESSURE/DISTANCE CURVE. FMT



ROUND 2. – PRESSURE/DISTANCE CURVE FMT RESULT



ROUND 4.-PRESSURE/DISTANCE CURVE FMT

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ATOMIC WEAPONS RESEARCH ESTABLISHMENT

AWRE REPORT No. T 4/65

B0153

OPERATION ANTLER

Air Shock Measurements

R. G. Turner

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[redacted]

(CLEARED FOR CANADA AND AUSTRALIA)

A.W.R.E.,
Aldermaston, Berks.

March 1965

[redacted]

Summary

On Operation Antler measurements were made of the shock overpressure/time relationship at sites down the main instrument lane, similar measurements at a few other isolated sites, and peak free air shock overpressure by a smoke rocket technique.

Three types of instrument were used. Two gave a pressure/time history of the shock wave at the recording site; the third, a measurement of the peak overpressure at the recording site.

The pressure/distance data for the precursor-free regions of the main instrument lanes have been compared with Foulness small charge data to give estimated total energy yields of:-

Round 1: 0.65 ± 0.05 kilotons ***100 ft tower burst***

Round 2: 6.86 ± 0.36 kilotons ***100 ft tower burst***

Round 3: 17.9 ± 0.9 kilotons. ***1,000 ft balloon suspended air burst***

Time of arrival data, positive phase duration and positive phase impulse data are included. Canadian measurements of the free air shock using a smoke rocket trail technique are reported elsewhere.

NOTE: blast peak overpressure determined yields above have a source of error in the assumed conversion between blast yield and total nuclear yield (usually assumed to be 45% in UK reports, 50% in USA reports), because the surface portion of the blast wave is subject to thermal flash convective heating of the air near the ground surface even where a precursor does not occur, when this extra energy thus added from the thermal flash to the blast, boosts the effective blast yield, just as neutron heating of air around the fireball boosts blast.

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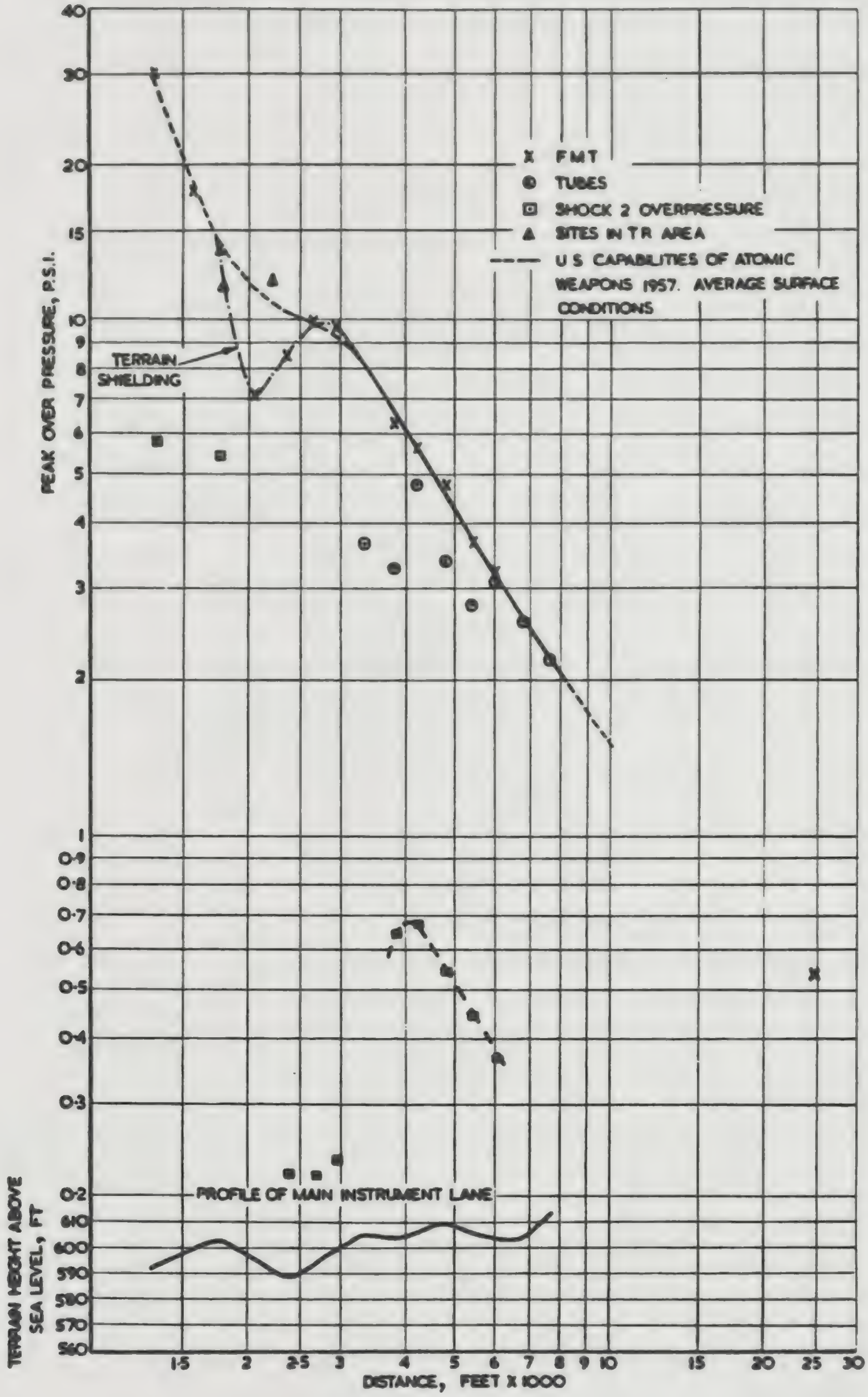

FIGURE 6. ROUND 3

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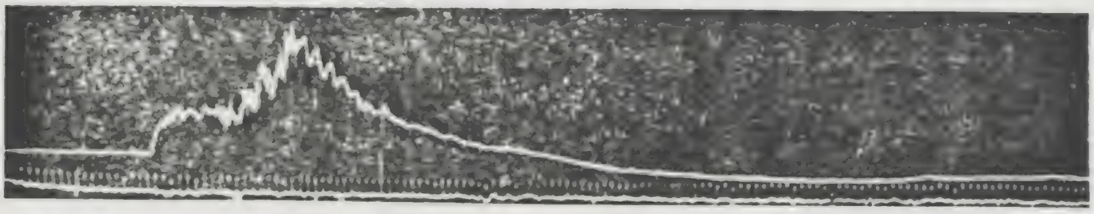
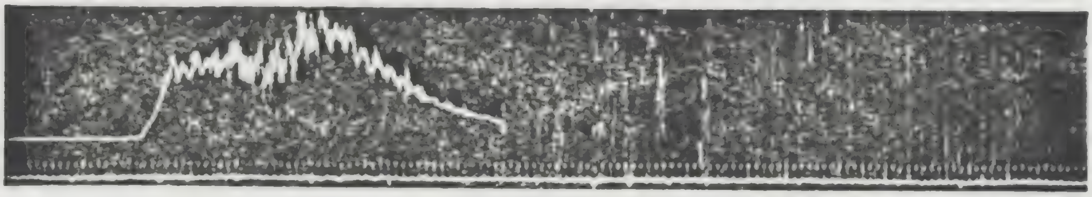
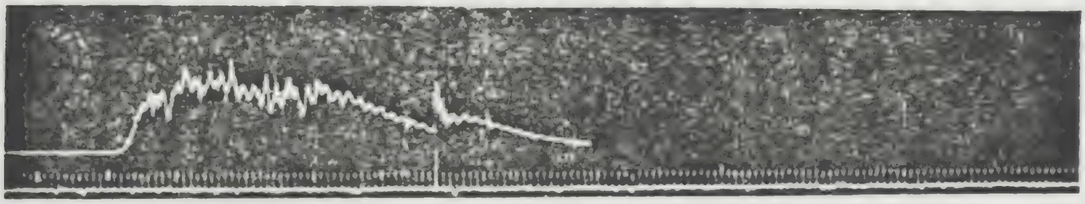


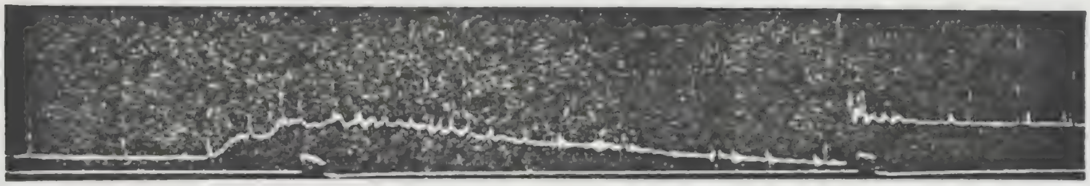
AG 516 1 353 FT 30·1 P.S.I.



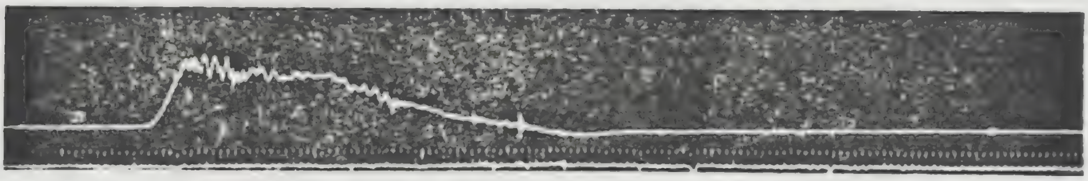
AG 517 1 601 FT 18·0 P.S.I.



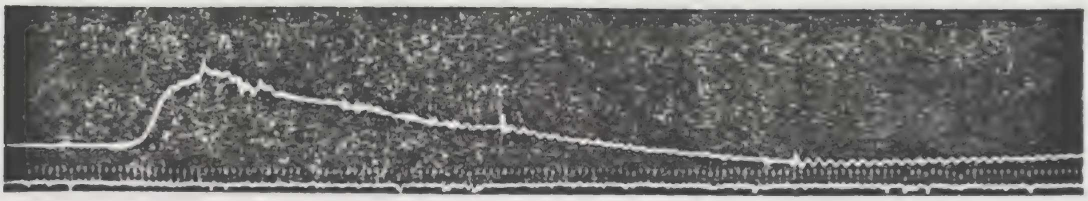
AG 512 1 800 FT 13·9 P.S.I.



AG 513 2 077 FT 7·17 P.S.I.



AG 514 2 395 FT 8·50 P.S.I.



AG 515 2 693 FT 9·99 P.S.I.

FIGURE 12 ROUND 3

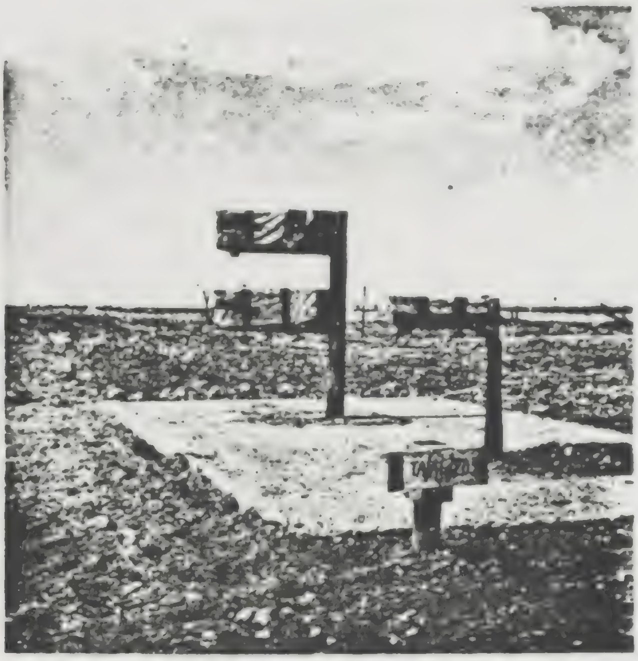


FIGURE 15. SITE AG 205 ROUND I. TYPICAL INSTALATION

FIGURE 16. SITE AG 513 ROUND 3. 2077 FT FROM GZ LOOKING FORWARD TO THE RIDGE AT 1700 FT

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Reference A8/633/58/CAA 0146

11/4/55 MINISTRY OF DEFENCE SC ... LONDON

6056 Permanent Proving Ground Trials 0171 JC

Admiral P.W.Brooking

U/c wrt Def Nuc Tech info 23/1/85

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Co 60 pellets found at Maralinga

DEFE 16/443

Halliday rang me this morning to say that Myers has been enquiring about the Co60 pellets found at Maralinga by Turner. I have tried, without success, to ring Myers to find his source of information and the reason why he is pursuing the matter. The facts are as follows:-

Co60 was used at Antler as a detector. With some difficulty I obtained permission from the Director to inform Titterton (as Chairman of the Safety Committee) that we intended to use such an indicator. Titterton was entirely sympathetic, raised no difficulties, realised that we were not adding any real hazard, and agreed that the information should go no further on the Australian side. Recently Turner, the Australian who is responsible for Health Physics at Maralinga in the inter-trial period, claims to have found Co60 in some pellets which he has collected and which we have arranged should be sent back to U.K. As soon as I heard of this I wrote to Titterton stating what the position was and suggesting that it would be as well if information on this subject were not extended any further in Australia. I have not as yet had any reply from him.

I shall not have an opportunity to get in contact with Myers today. Tomorrow evening I leave for Risley and expect to be in again on Friday. You may think it worthwhile to get in touch with Myers. The fact that he is asking questions on the subject suggests that the information has already received a wider circulation than I thought it would.

/Since

12th August, 1958

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Since dictating the above I have had a call from Frankie Lloyd who raised the matter of Co60 amongst other things. It appears that Turner has reported to Dick Durance in addition to reporting here. In doing so I think Turner has misconstrued his terms of reference which were to report in the first instance to A.W.R.E. The correspondence will be sent down here by Frankie. I hope that I shall shortly have a reply from Titterton but at present I do not know how to get in touch with him. I have asked Mrs. Prosser to find from Australia House where Titterton can be contacted. If it is necessary to correspond with the Australian Department of Supply or the Range Commander, I should much prefer to do so in terms agreed with Titterton, rather than to write indepdently.

C.A.A.

C. A. Adams
C.T.

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 37/58

OPERATION ANTLER

32

Target Response Group
(Group Leader Plans: E. R. Drake Seager)
(Group Leader Operations: Lt.Col. E. T. Wray, REME)

The Shielding from Initial Radiation Afforded by Soil

Maj. D. B. B. Janisch, RA

[redacted]

A.W.R.E.,
Aldermaston, Berks.

[redacted]

November, 1958

[redacted]

1. Introduction

On Operations Hurricane, Totem and Buffalo, trials were carried out to measure the protection from initial radiation afforded by various fieldworks and AFVs. The most recent of these trials (Operation Buffalo) is reported in Ref. [1].

After Operation Totem, Major L. Cave, RAOC, who had carried out some shielding trials, made recommendations for future trials (which are included as an Appendix to Ref. [1]). Some of the recommended trials were included in the plan for Operation Buffalo.

When analysing the results obtained at Operation Buffalo, it became clear that it was desirable to obtain more information about the shielding capabilities of earth in circumstances where confusion of the results by scattered radiation could not occur. After Operation Totem, one suggestion was to sink a small diameter pipe into the earth, and to place therein dosimeters at different depths. While making the initial preparations for the Antler trial, it was thought desirable to measure neutron fluxes as well as the γ-dose at different depths, because it had been shown in Ref. [1] that in some circumstances, the neutron hazard in a shielded position is as great as, or even greater than the γ-hazard. To accommodate neutron dosimeters, it was necessary to use a pipe of wider diameter than had originally been suggested; this necessitated a change in the method of the trial, which is described in detail in Section 3.2 below.

The protection afforded by the earth against neutrons, and against γ-radiation, has been treated separately in the remainder of the report.

As in previous reports, the Protection Factor (PF) has been defined as:-

$$PF = \frac{\text{Free air dose or flux at site}}{\text{Dose measured at particular point in shielded position}}.$$

2. Objects of the Trial

The objects of the trial were firstly to determine the protection factors afforded at various depths in soil, against γ-radiation and thermal and fast neutrons, and secondly to investigate any variation of these protection factors with distance from point of burst, weapon design or height of burst.

3. Method

3.1 Types of Dosimeter Used

3.1.1 γ-Dosimeters

It was decided to use three types of γ-dosimeter:-

(a) Service Phosphate Glass.

(b) AWRE Film/Phosphor.

(c) Service (or Service Type) Quartz-Fibre. Three varieties of these were used:-

(i) Type QF(A) The Prototype Dosimeter No. 5 used at Operation Buffalo.

(ii) Type QF(B) The Service Dosimeter No. 5.

(iii) Type QF(C) QF(B) with the ionisation chamber partially evacuated to 1/3 atmospheres and with the capacitance adjusted accordingly.

The differences between these three types of quartz-fibre dosimeter, and the reasons for their use are discussed in detail in Section 4.2 below.

3.1.2 Neutron Dosimeters

The standard AWRE method of neutron dosimetry [1] is to expose samples of pure elements in a steel tube 18 in. long, 2 in. external diameter and about $\frac{1}{4}$ in. wall thickness. The elements become radioactive on irradiation and it is possible to measure fast (greater than 3 MeV) neutrons using sulphur*, total slow neutrons using unclad gold† and epithermal neutrons using gold clad with cadmium. The thermal neutrons may then be obtained from the latter two results by subtraction.

For the present trial a modified form of the AWRE standard tube was used. This was 6 in. long, 2 in. external diameter and about $\frac{1}{4}$ in. wall thickness and contained three discs, one of gold, one of gold wrapped in cadmium and one of sulphur. A tube, with its contents, is shown in Figure 1.

3.2 Positioning of Dosimeters

The original suggestion was to sink a 2 in. diameter pipe into the ground; the angle subtended at the mouth of the pipe by any distance-piece separating dosimeters would then have been sufficiently small for its density to be unimportant. In this trial, however, it was necessary to accommodate the neutron dosimeters as well, and as it was essential that all three elements in these dosimeters should be at

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* $^{32}S\ (n,p)\ ^{32}P$. (Half-Life = 14.3 days).

† $^{197}Au\ (n,\gamma)\ ^{198}Au$. (Half-Life = 2.69 days).

4.2 Reliability of Results

4.2.1 Quartz-Fibre Dosimeter

Certain types of quartz-fibre dosimeter are liable to read low when measuring large doses of γ-radiation delivered over a very short period of time [1], [2], [3]. To give the reasons for the decisions which are made below, it is necessary to give a brief resume of the situation regarding Service QF dosimeters over the period covering Operations Buffalo and Antler.

Originally, quartz-fibre dosimeters intended for measuring initial radiation (as opposed to residual radiation), were designed on the assumption that the substantial portion of the dose would be delivered at a dose-rate not exceeding 100 r/sec. As a result of experience on Operation Buffalo, it was decided that the Service dosimeter QF No. 5 should be calibrated so as to read full-scale doses accurately when delivered at dose-rates up to 600 r/sec [4]. This was possible for two reasons, firstly that the Service design (type QF(B) in this report) had improved geometry compared with the prototype (QF(A)), and secondly, that the scale had been adjusted so that at dose-rates not exceeding 600 r/sec, the dosimeter would read within ± 20% as opposed to + 0% − 40% as with the type QF(A).

On examination of the present results, it was found that discrepancies of up to a factor of more than 2 existed between the phosphate glass dosimeter results and those of the quartz-fibre (QF(B)) dosimeters. Even greater discrepancies were found in the case of the QF(A) dosimeters. These variations were discussed with members of the RM Group, and with the members of the Electronics Division of AERE who are concerned with the development of these dosimeters (Messrs. W. Abson, D. Peirson and F. B. Whiting). As a result of these discussions, three solutions seemed possible:-

(a) A greater sensitivity to neutrons in the case of the phosphate glass dosimeters.

(b) An inferior response by the quartz-fibre dosimeters due to the γ-radiation of energies greater than 2 MeV received from the radiative capture of neutrons in the atmosphere, **together with** the fact that any γ-radiation stemming from the neutron flux will be delivered at a high dose-rate.

(c) Increased errors in the quartz-fibre dosimeters because a substantial portion of the total dose may be delivered at a dose-rate considerably in excess of 600 r/sec.

These different possibilities of errors arising are discussed below:-

(a) Neutron Sensitivity

Phosphate glass and quartz-fibre dosimeters have been irradiated under similar conditions in a thermal reactor, and it was found that, for thermal neutrons, the sensitivity of the two types was similar and that a neutron flux of 10^{10} thermal neutrons/cm^2 enhanced the reading of either type of dosimeter by about 1 r. At the time of writing this report (February, 1958), little information was available on the relative sensitivity to neutrons with energies greater than thermal, but there is an indication that the response of both types of dosimeter to these energy neutrons is similar [6].

(b) **Variations in Energy of Incident γ-Radiation**

Differences in the surface densities of the two types of dosimeter will tend to make the quartz-fibre dosimeters read slightly low when measuring radiation with energies greater than the 2 MeV associated with the initial radiation from the cloud itself. In Ref. [7] it is shown that for the radiative capture of neutrons in the atmosphere (of which the reaction $^{14}N\ (n,\gamma)\ ^{15}N$ is one of the more important), a large proportion of the γ-photons have energies of greater than 5 MeV and some are of energies exceeding 10 MeV. In the same reference, it is suggested that, for low neutron-escape weapons, the contribution to the total γ-dose from the neutron capture reaction does not exceed 20%. It is reasonable therefore to assume that for Antler Rounds 2 and 3, where the neutron-escape was larger, the contribution of the higher energy (radiative capture) γ-rays to the total γ-dose was probably more than 50%.

Three individual errors can therefore be introduced by this:-

(i) The direct error due to the varying response of the instrument to γ-photons of different energies.

(ii) The fact that there will be greater attenuation of the lower energy (cloud) γ-radiation by the earth, so that in the deeper positions in the holes, the high energy (radiative capture) γ-rays will constitute a greater proportion of the total dose.

(iii) The time over which the two components of the γ-dose is delivered. This is discussed in more general terms below.

(c) Errors from High Dose-Rate

This seems to be the most probable source of error. The RM Group records show that in Antler Rounds 2 and 3, at 6000 ft from Ground Zero, approximately 35% of the total dose was delivered in 0.01 sec, and 76% in 0.3 sec* [5]. Application of these figures to a total dose of the order of 500 r. (the full-scale deflection on the dosimeter QF No. 5), shows that a large proportion of the dose must have been delivered at dose-rates considerably in excess of 600 r/sec. There is little practical confirmation that this will explain the very low relative readings of the quartz-fibre dosimeters compared with the phosphate glass, as it is not possible to simulate such high dose-rates in the laboratory with any degree of accuracy. However, it is reasonable to assume that the phosphate glass dosimeter should show less errors from high dose-rates (as it is the collection of dislodged **electrons** which is concerned in the measurement), than would the quartz-fibre dosimeter where comparatively heavy **ions** have to be collected. There is some additional confirmation from the partially evacuated quartz-fibre dosimeters (type QF(C)), which show smaller errors than the others.

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* The data given here of the proportion of the dose delivered over different periods of time include the increased dose-rate due to the γ-rays from the radiative capture of neutrons in the atmosphere.

detected and measured in this trial. The necessity of measuring these intermediate neutrons was discussed in Ref. [1], but at the time of preparing for Operation Antler, there was no really reliable method of measuring them readily available.

5. Discussion

5.1 γ-Dosimetry

(a) Round 2

From the results of the γ-radiation measurements made on Round 2 (an approximately 5 kiloton weapon burst on a 100 ft tower), it will be seen that the protection factors which were obtained in hole BI2 (1800 ft) are exceptionally high and are generally quite different from those obtained at similar depths at other positions. There is also a probably spurious low factor at 60 in. at position BI3 (2100 ft), and as this factor is determined by only one set of dosimeter results, too much reliance should not be placed on it.

In Appendix A to Ref. [1], it was suggested that for planning purposes, the following protection factors (Table 2) should be used for a ground (or low tower) burst. Mean factors obtained at Antler Round 2 are given for comparison.

TABLE 2

Predicted and Measured Protection Factors: Round 2

Depth, in.	6	12	24	36	48	60
Predicted P.F.	5	30	250	2000	2×10^4	2×10^5
Mean P.F. Obtained	2	5	30	300	2000	5000

Individual factors will of course vary appreciably from the "mean P.F. obtained" quoted above, but these latter figures are considered to be reasonably representative.

(b) Round 3

In the case of Round 3, (a balloon-burst at about 1000 ft of a 25 kiloton weapon) there were, unfortunately, some serious discrepancies between readings obtained by phosphate glass and film/phosphor dosimeters at 48 in. depth at positions TA4, TA5 and TA6. The results which are available are compared with those predicted in Ref. [1] in Table 3 below.

TABLE 3

Predicted and Measured Protection Factors: Round 3

Depth, in.	6	12	24	36	48	60
Predicted P.F.	1.7	10	80	400	4000	4×10^4
Mean P.F. Obtained	1.3	3	15	85	1000	$3\frac{1}{2} \times 10^3$ to $2\frac{1}{2} \times 10^4$

It will be seen that in the case of both rounds, the protection factors obtained were appreciably lower than those which were suggested. (It must be emphasised that the author of those suggestions said at the time that accurate prediction was very difficult.)

The manner in which the well-boring machine deposited the spoil on the surface made it impossible to analyse the material being bored out; Figure 4 shows typical spoil. One possible explanation of the higher protection factors measured at position BI2 would be that the hole was bored into sand instead of limestone; there was however no sign of this in the spoil. It would of course be possible for the area of the hole to be surrounded by a pocket of higher density sand although the hole itself was bored in limestone - this is considered unlikely.

References

1. Maj. D. B. B. Janisch, et al.: "Operation Buffalo - The Shielding from Initial Radiation Afforded by Fieldworks and AFV's". AWRE Report No. T3/57.

2. Maj. D. B. B. Janisch et al.: "Operation Buffalo - Field Trials of Radiac Instruments in a Radioactively Contaminated Area" AWRE Report No. T2/57.

3. D. H. Peirson: "Operation Buffalo - Measurements with Phosphate Glass and Quartz-Fibre Dosimeters in the Field". AWRE Report No. T26/57

4. G. C. Dale: Private communication on Operation Buffalo - January, 1957

5. G. C. Dale: Private communication on Operation Antler - February, 1958.

6. D. H. Peirson and F. B. Whiting: Private communication - February, 1958.

7. R. A. Siddons: "Gamma Emission Resulting from the Radiative Capture of Neutrons by Nitrogen During an Atomic Explosion". AWRE Report No. E5/54.

8. Maj. D. B. B. Janisch: "Operation Antler - Neutron Induced Activity. AWRE Report No. T35/58.

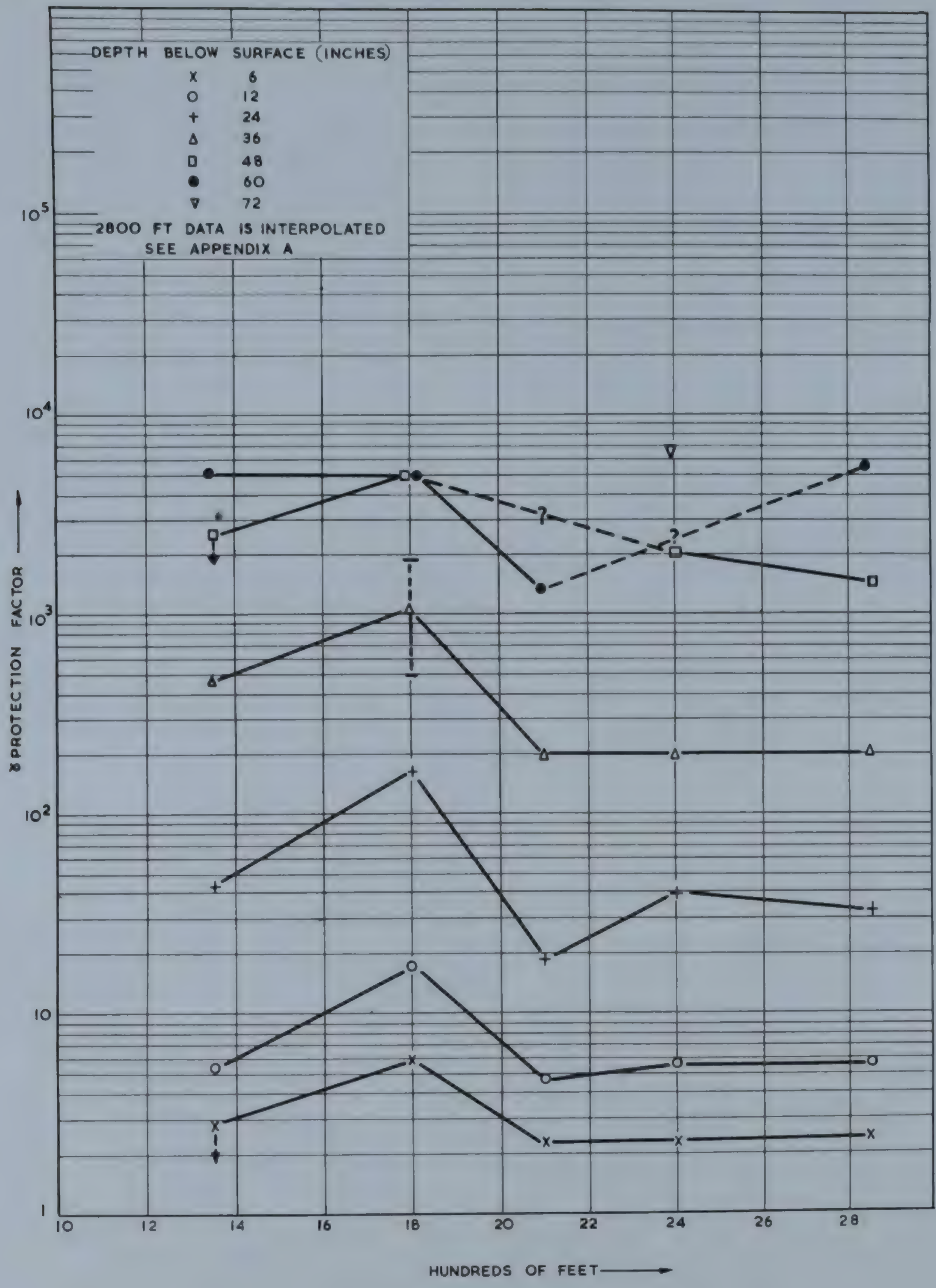

FIGURE 7a. ROUND 2 γ RADIATION PROTECTION FACTORS

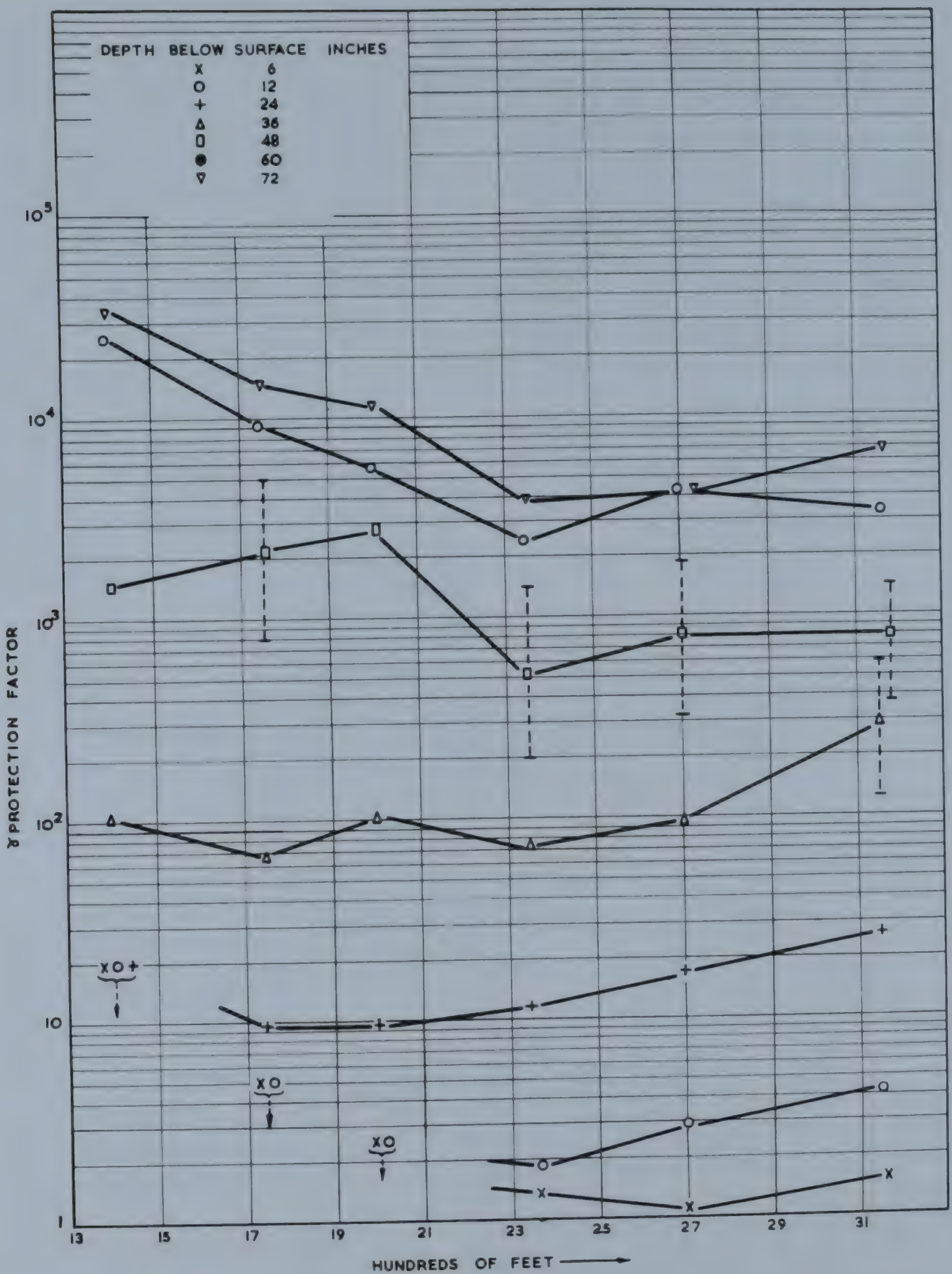

FIGURE 7b. ROUND 3 γ RADIATION PROTECTION FACTORS

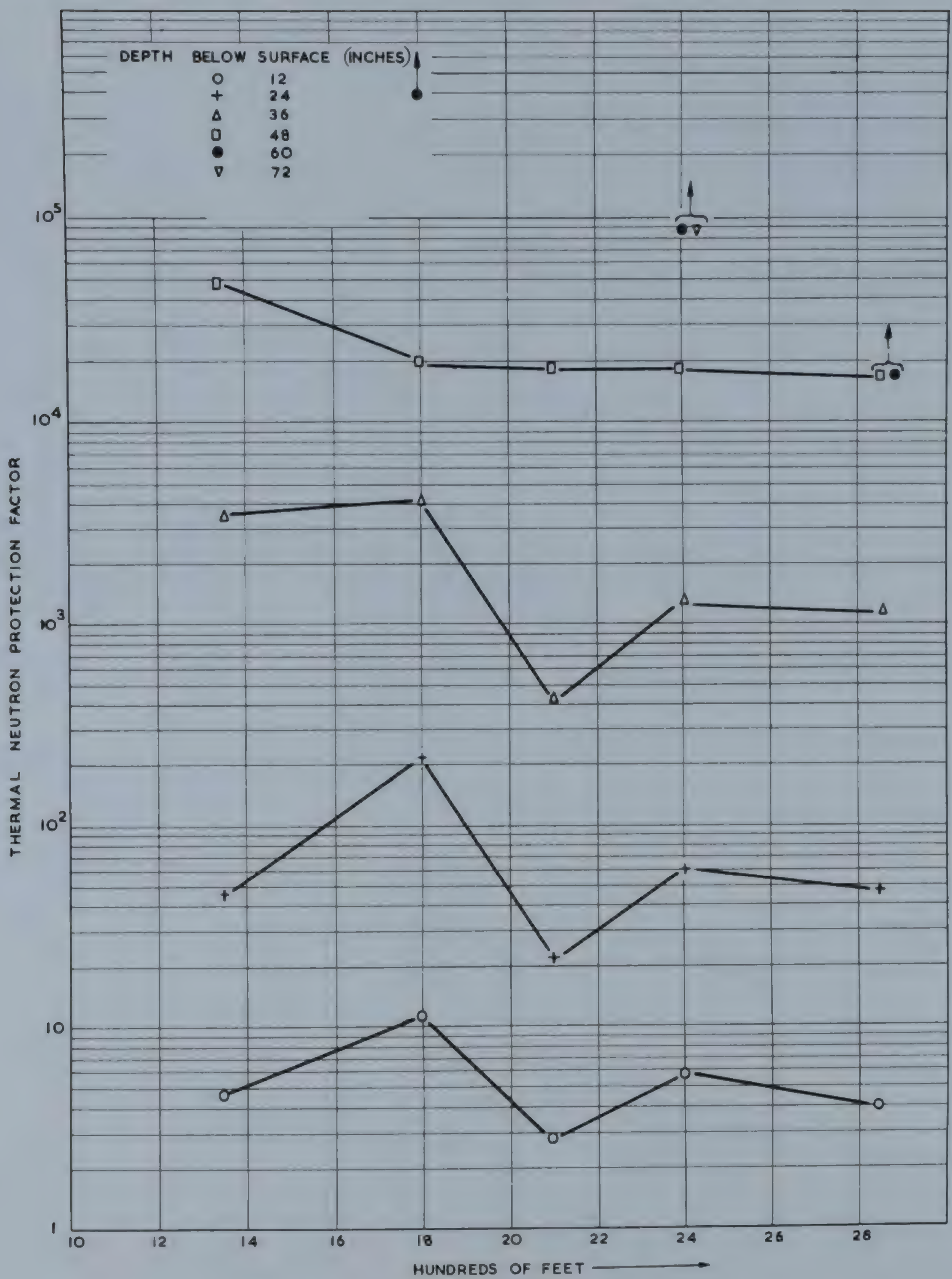

FIGURE 8a ROUND 2 THERMAL NEUTRON PROTECTION FACTORS

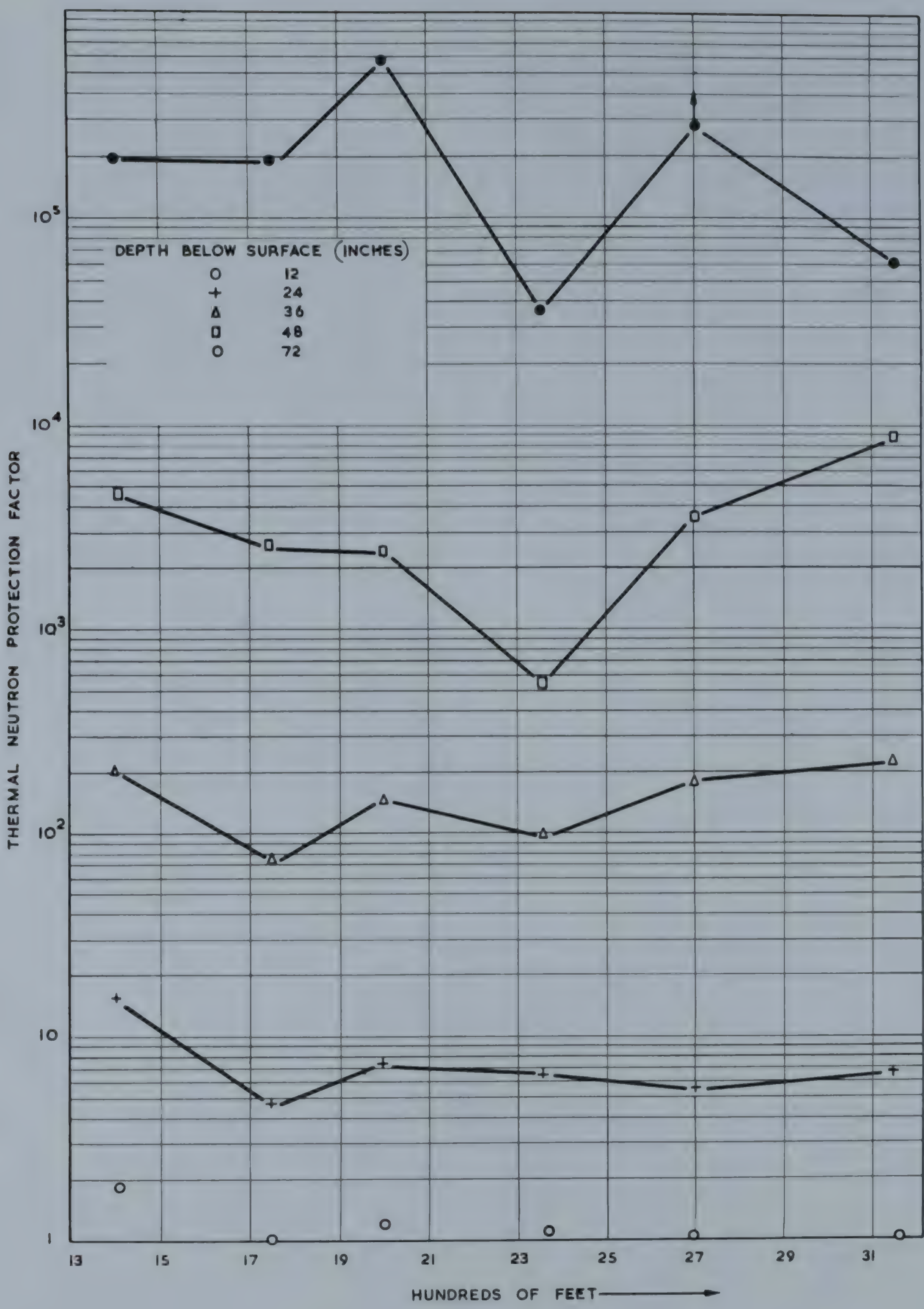

FIGURE 8b. ROUND 3 THERMAL NEUTRON PROTECTION FACTORS

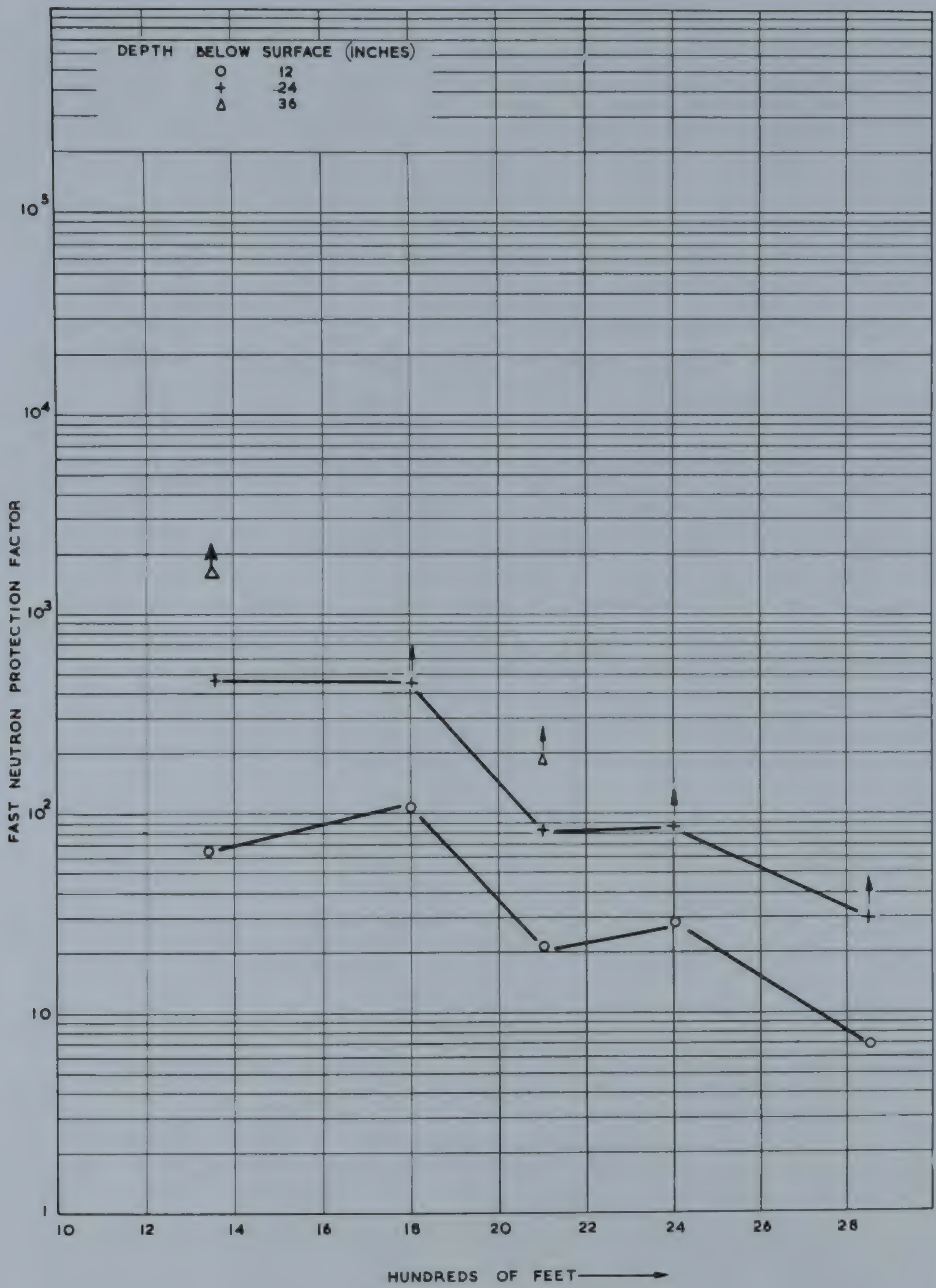

FIGURE 9a. ROUND 2 FAST NEUTRON PROTECTION FACTORS

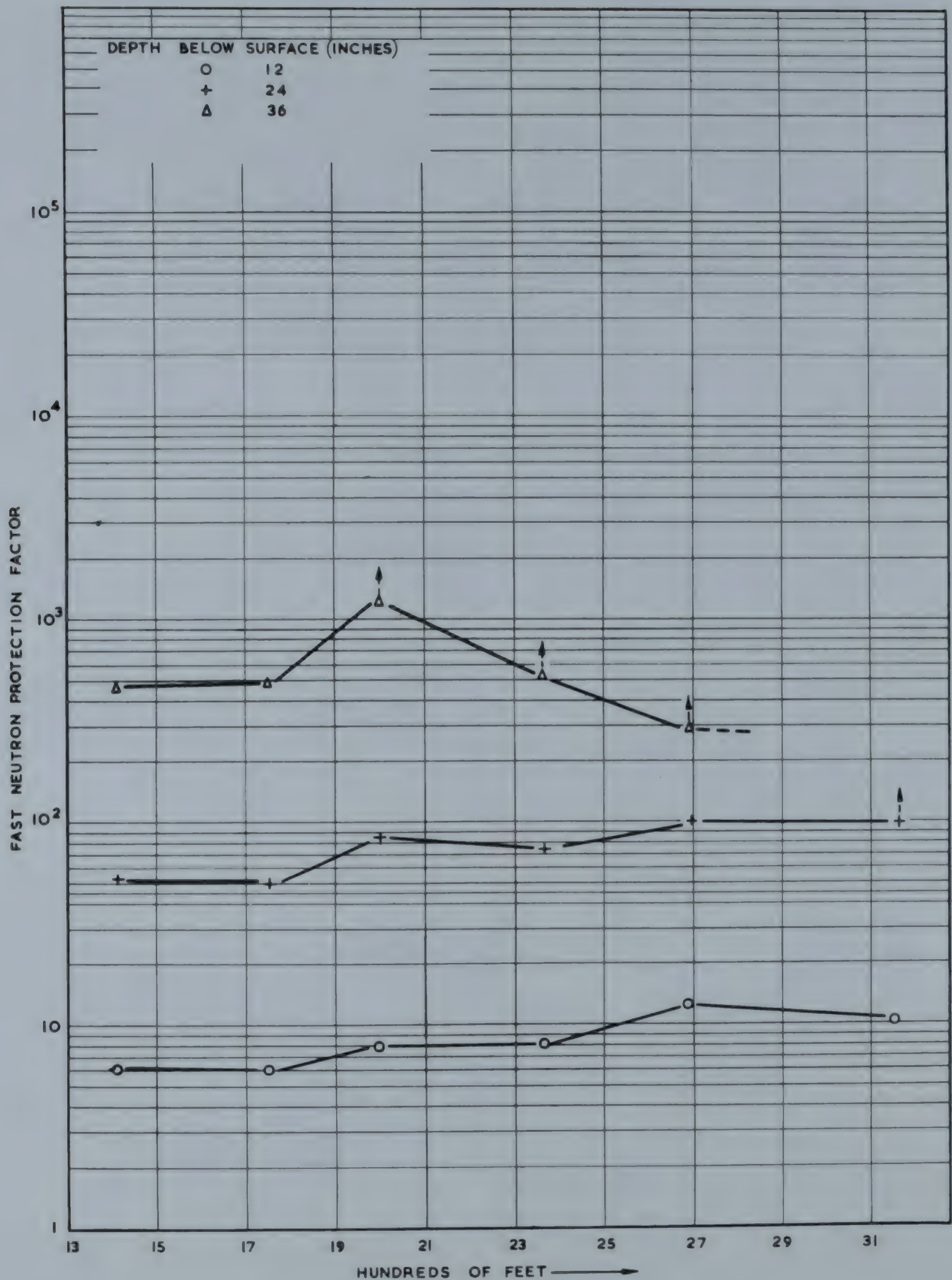

FIGURE 9b ROUND 3 FAST NEUTRON PROTECTION FACTORS

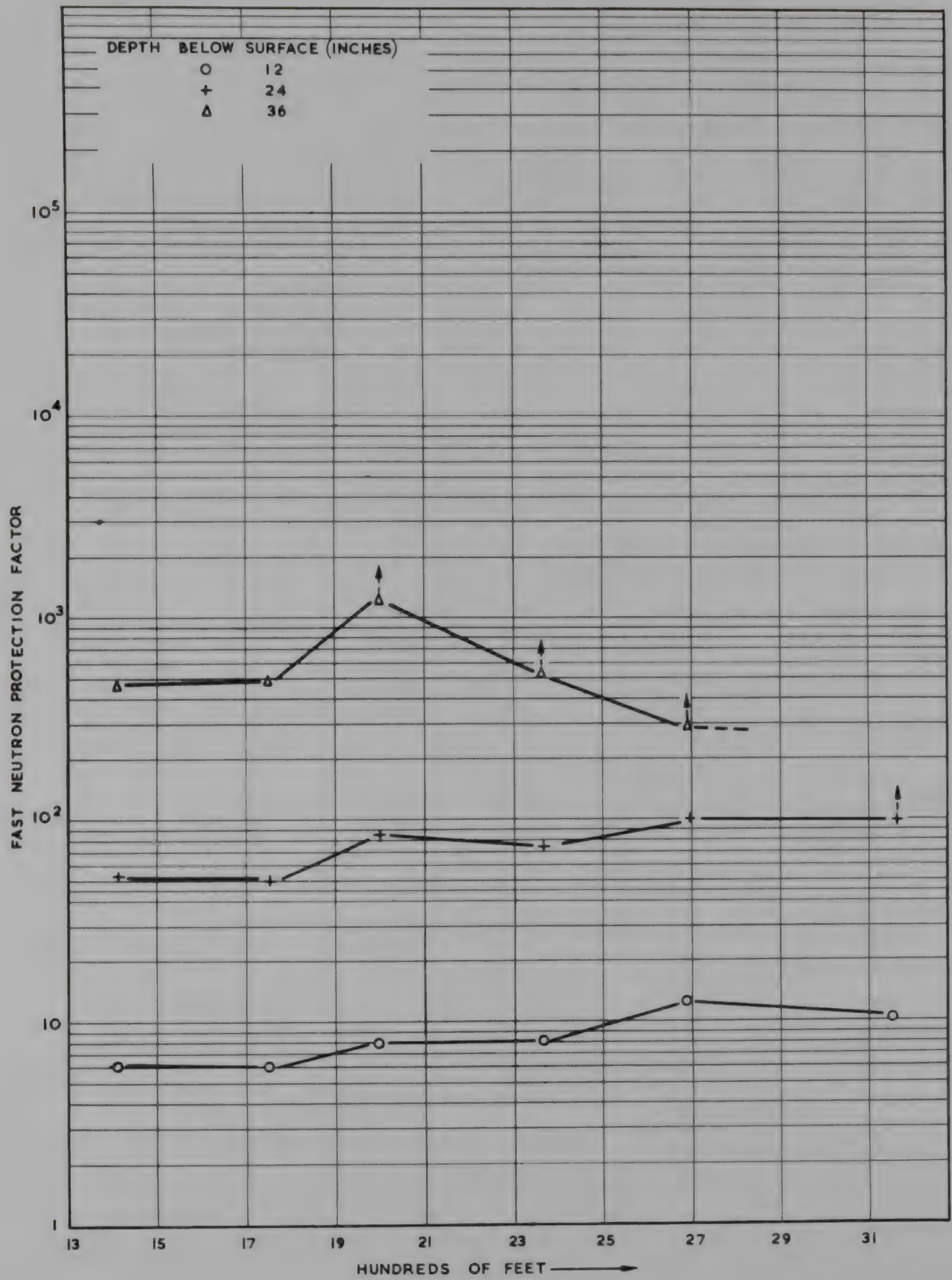

FIGURE 9b ROUND 3 FAST NEUTRON PROTECTION FACTORS

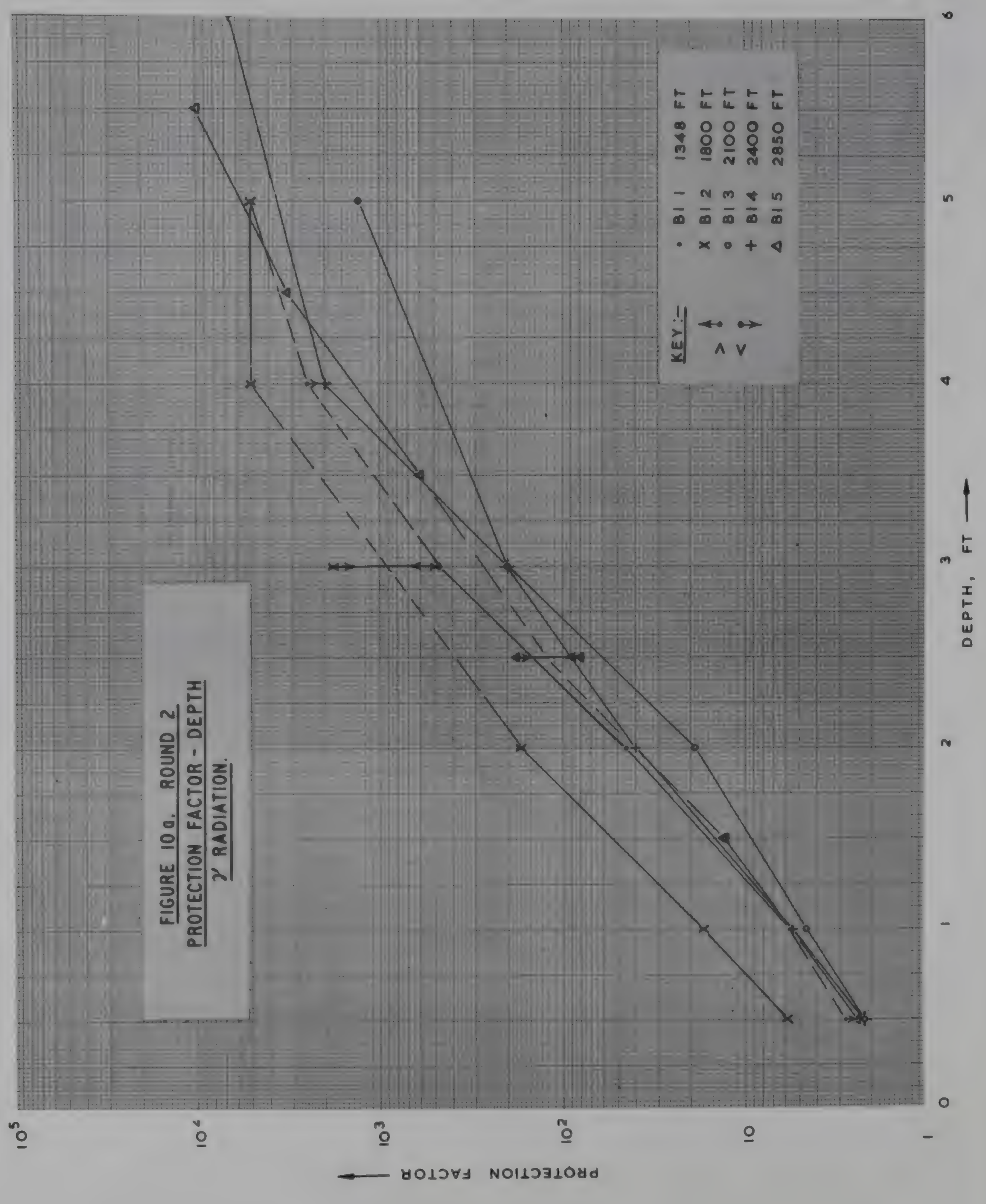
FIGURE 10a. ROUND 2
PROTECTION FACTOR - DEPTH
γ RADIATION.
KEY:-
· B1 1 1348 FT
X B1 2 1800 FT
∘ B1 3 2100 FT
+ B1 4 2400 FT
Δ B1 5 2850 FT
PROTECTION FACTOR
DEPTH, FT
0
1
2
3
4
5
6
1
10
10²
10³
10⁴
10⁵

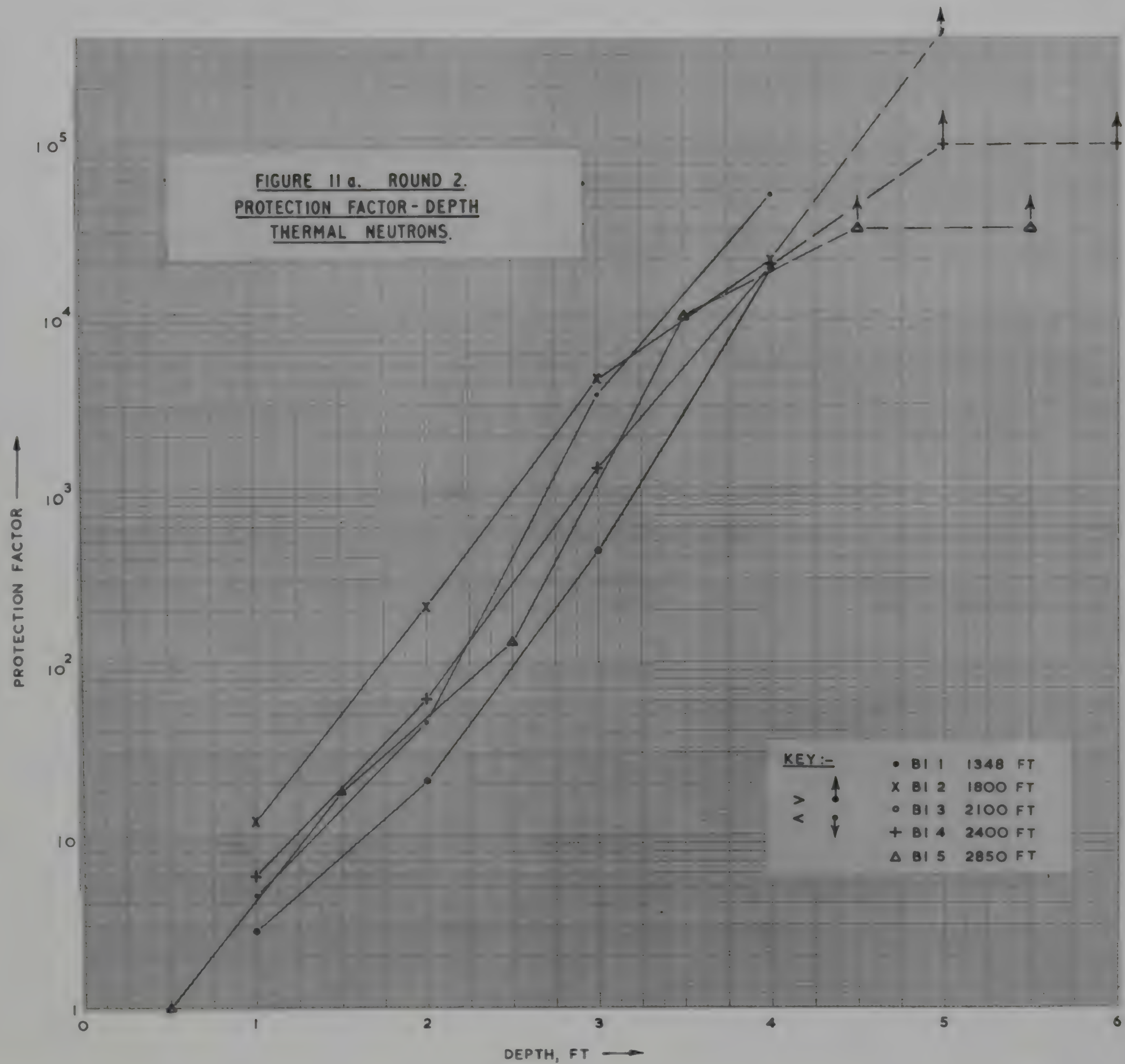

FIGURE 11a. ROUND 2.
PROTECTION FACTOR - DEPTH
THERMAL NEUTRONS.

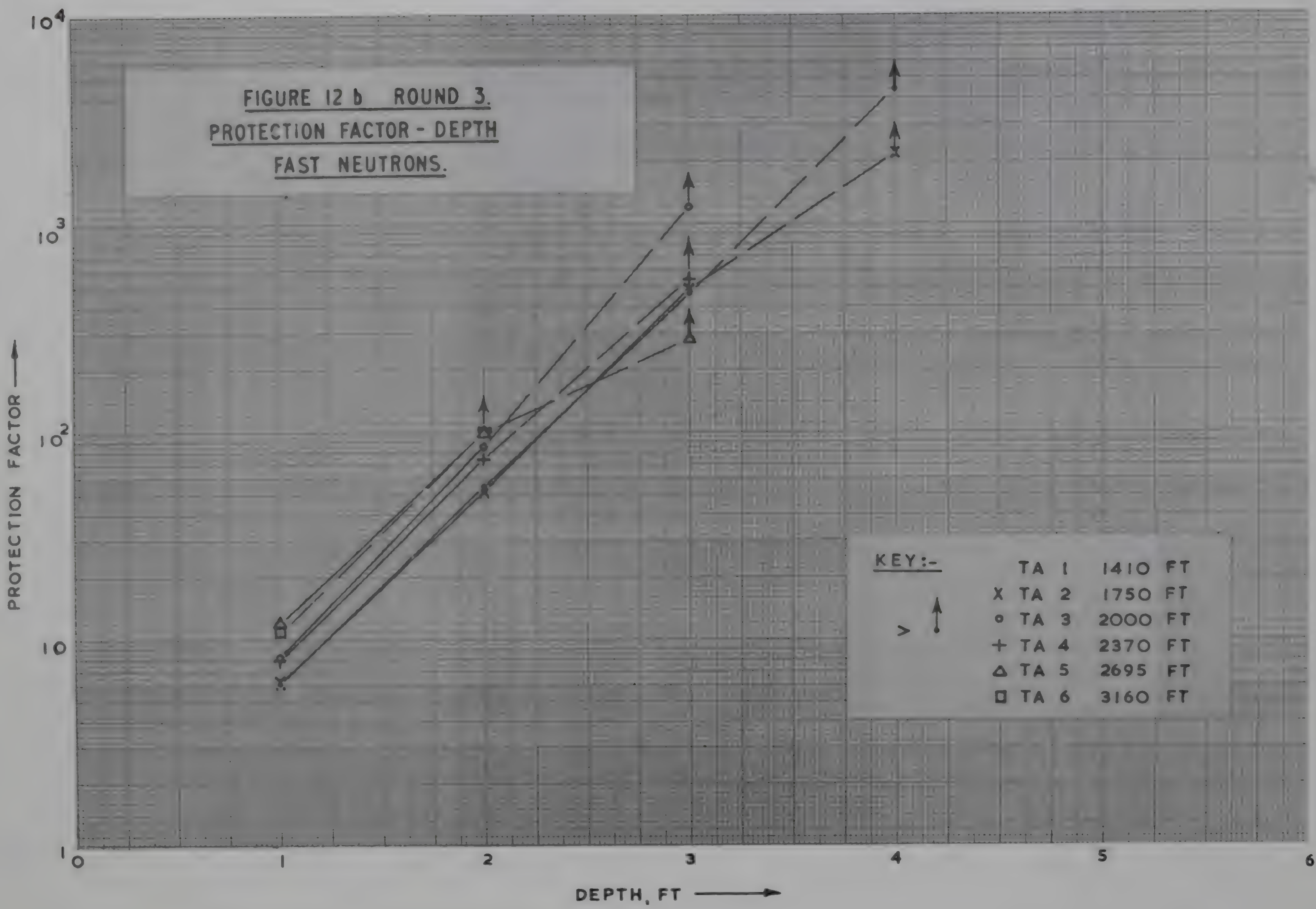
FIGURE 12 b ROUND 3.
PROTECTION FACTOR - DEPTH
FAST NEUTRONS.
KEY:-
>
TA 1 1410 FT
X TA 2 1750 FT
o TA 3 2000 FT
+ TA 4 2370 FT
△ TA 5 2695 FT
□ TA 6 3160 FT
PROTECTION FACTOR
DEPTH, FT
10^4
10^3
10^2
10
1
0
1
2
3
4
5
6

Casualties from British WWII Blast Effects data as applied to nuclear war caused arguments with American disarmament activists. As this file shows, Britain took 10 psi peak overpressure as the 50% blast mortality rate for the population in houses, based on actual data, e.g. in the complete destruction of British houses within 77 feet from V1 "flying bombs" (Hitler's cruise missiles), mortality was 23.5% (Christopherson's RC-450, Table 8.2 on p145). This "confidential" data (used in 1972 DNA-EM-1 Table 10-1) agrees with "secret" American data from Hiroshima, but is much less than the 50% assumed in unclassified American reports.

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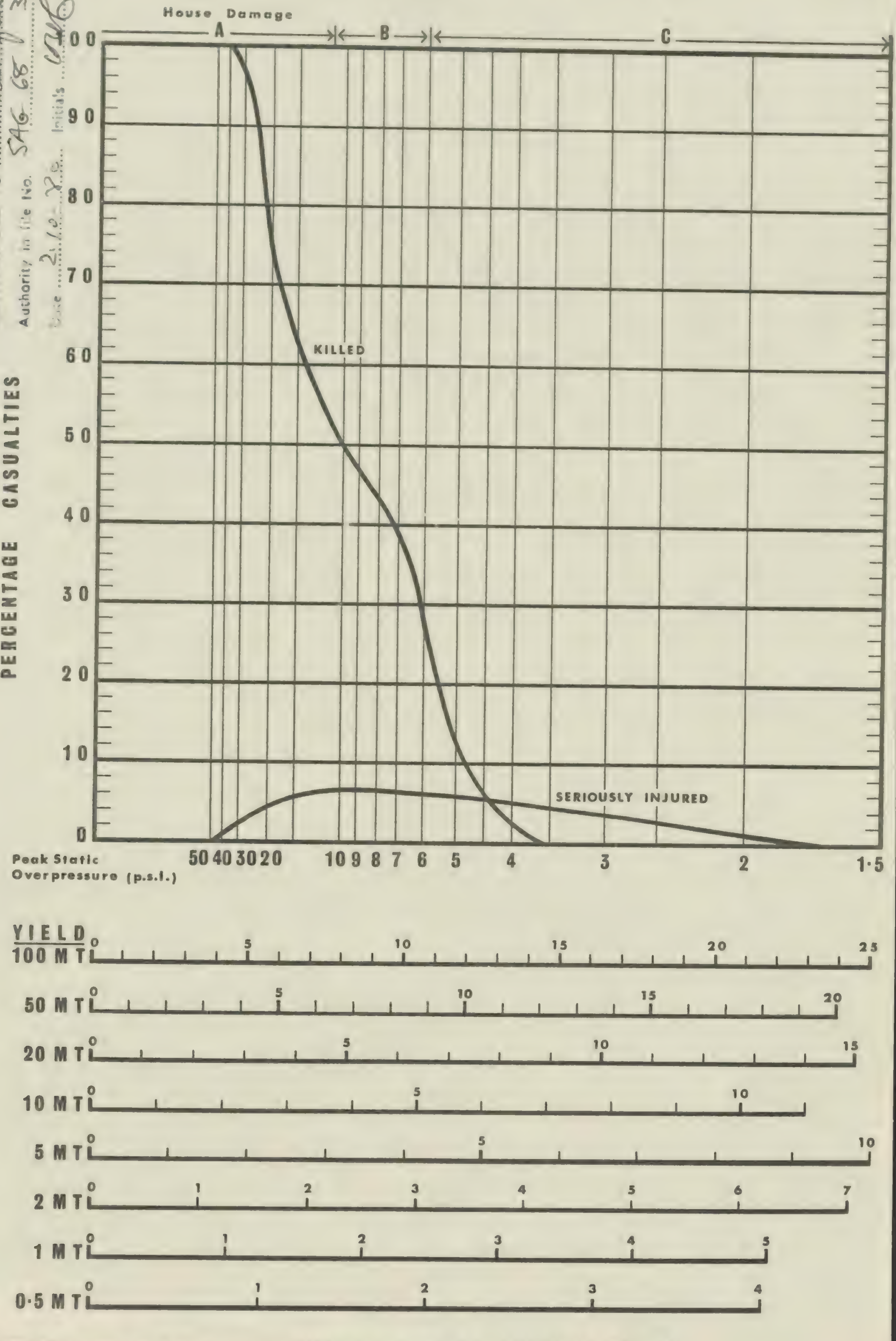
CASUALTIES DUE TO IMMEDIATE EFFECTS OF GROUDBURSTS

People protected from heat flash in British houses



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Confidential

R & M 45

Home Office
Scientific Advisers' Branch

Casualty Rates for a Ground Burst 10 MT Bomb omitting Residual Radiation - all in houses

Casualty rates for an air burst megaton weapon can be obtained by simple scaling up from kiloton weapons. For ground bursts the scaling is a little more complex and in this note comparable rates for a 10 MT groundburst bomb have been estimated.

Method of calculation

A 10 MT groundburst bomb gives a radius for A damage to houses of $3\frac{1}{2}$ miles, B damage 5 miles Cb damage 8 miles and Ca damage 13 miles.

The death risk curve (X Y Fig 1) is derived from Fig 3 of Appendix 2 of C.D.J.P.S. (EA)(48)14 for secondary blast and debris casualties (houses - complete rescue). Since deaths in houses from secondary blast are related directly to the degree of damage of the house the distance scale has been expanded proportionately and the curve gives the corresponding version of deaths for secondary blast for a 10 MT groundburst bomb. There is also however a contribution of deaths due to gamma flash although this is distributed differently from that occuring with a kiloton explosion. The LD 50 in the openfor a 10 MT bomb is 4,800 yards (= 2.7 miles) corresponding to $\frac{3}{4}$ mile for a nominal bomb. A dose of 10,000r in the open causes 30% deaths for people in houses. This dose would occur at 2,100 ft. from a nominal bomb or 2.2 miles from a 10 MT bomb. The point of mid-area range for A damaged houses is 2.45 miles and at this point 35% deaths would occur from debris and 19% from initial radiation making a total of 54%. This is therefore taken as the average fatal casualty rate for people in A damaged houses against a 10 MT groundburst bomb.

For people in B damaged houses initial gamma makes no appreciable contribution to deaths and so the secondary blast rate of 6% at the mid-area point is taken as the average figure. Curve Y Y is the death risk curve for secondary blast and initial gamma combined.

The above figures are for immediate or inevitable delayed deaths. A proportion of people will be trapped and will die if not rescued. These people are classified as "alive but trapped" and they may be seriously injured, slightly injured or uninjured. In addition there will be people not trapped who are seriously injured or slightly injured or uninjured. The figures plotted in Fig. 1 for these categories were obtained by comparing Figs. 3 and 4 of Appendix 2 of C.D.J.P.S.(EA)(48)14 at the relevant points and adjusted to allow for the fact that the percentage deaths have been increased to include the initial gamma hazard.

Table I summarises the casualty rates obtained by the above means. It will be noted that very small percentages have been added for annuli in which casualties should not theoretically occur. These are purely adventitious figures added to give realism when the table is used for estimating casualties for exercises. Percentages have been worked out for Cb and Ca damaged areas separately but as this breakdown of the C damaged area is no longer officially recognised separate percentages are given also for the C area as a whole.

It must be emphasised that death and injury resulting from residual radiation, including fallout, are not included in these figures.

O.S.A. 42/8/5
E.C.A.

May, 1956.

CONFIDENTIAL

TABLE I

Percentage Blast Casualties (ignoring residual radiation) resulting from the ground burst of a 10 megaton weapon (All in houses)

Distance from G.Z. (miles)	Category of Damage	Killed	Alive but trapped			Untrapped	
			S.I.	L.I.	U.I.	S.I.	L.I.
0 - $3\frac{1}{2}$	A	54%	11%	6%	16%	5%	4%
$3\frac{1}{2}$ - 5	B	6%	6%	6%	24%	7%	5%
5 - 13	C	0.2%*	0.6%	0.13%	0.13%	2%	1.7%
5 - 8	Cb	0.4%*	2%	0.5%	0.5%	6%	5%
8 - 13	Ca	0.1%*	-	-	-	0.5%*	0.5%

* These are token figures added for exercise purposes to give a few casualties beyond the range in which they would normally occur.

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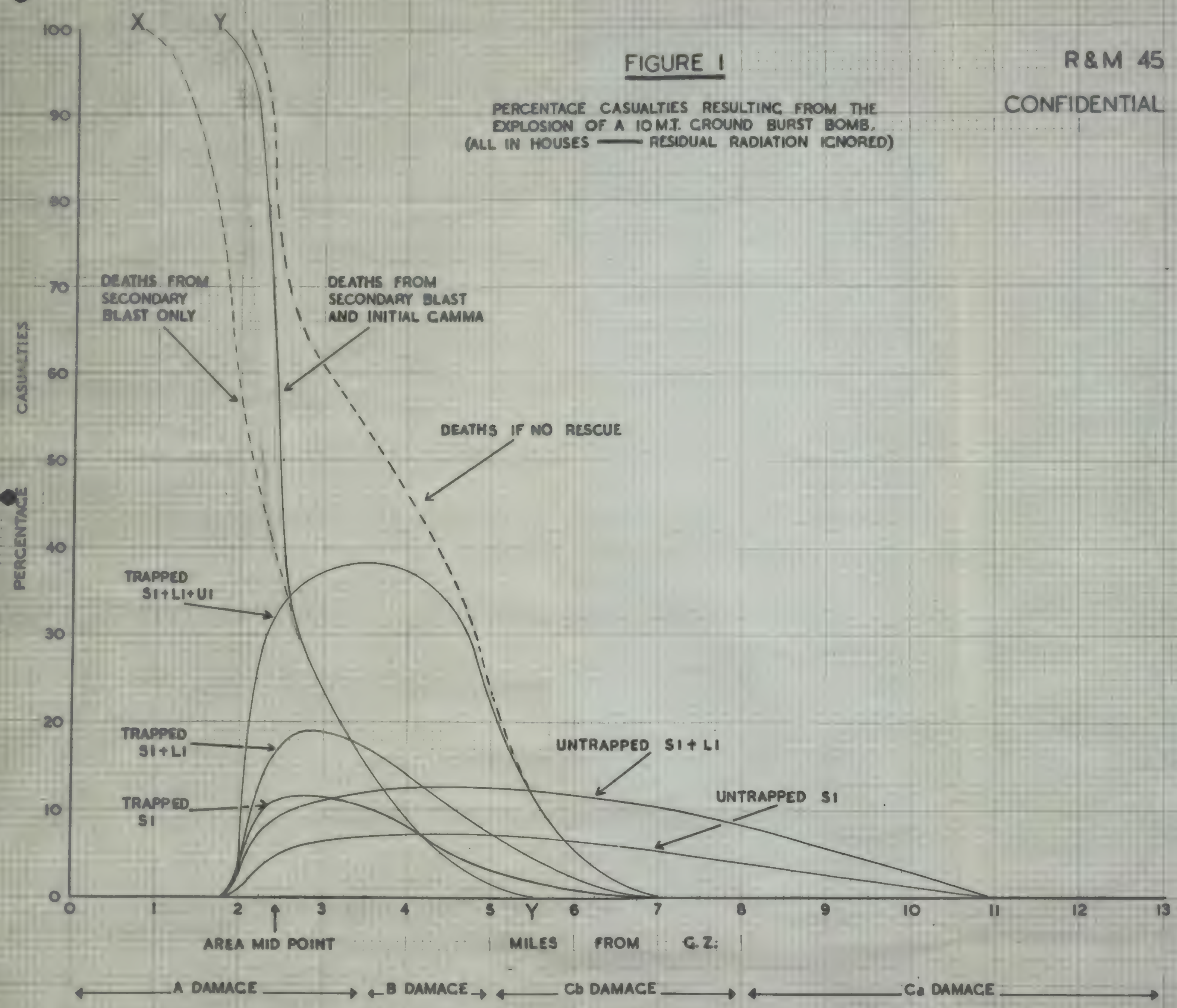


C.D. 16232

HOME OFFICE

SA/PR 106

SCIENTIFIC ADVISER'S BRANCH

Distribution of basement fallout shelters by size

1. A pilot survey of communal fallout shelters was carried out in 1964/65. The shelters were the basements of communal buildings and the survey was carried out in the counties of Leicester, Hereford, in two London districts and four Scottish districts.

2. One of the purposes of the survey was to find how much of such shelter was available assuming that it would be occupied only by people in lightly built dwellings such as bungalows, prefabricated houses and caravans. In such dwellings it was considered that fallout protection would not be adequate nor could it be rendered adequate by improvised improvements. The amount available varied widely between districts, some having none and others more than was required. Details are given in a Scientific Adviser's Branch paper: SA/PR 94(Revised).

3. The Working Party on Shelter Survival Requirements at its meeting on 5th April,1966, considered among other things the possibilities of providing a medical package for use in communal shelters. It was pointed out that the make-up and size of such a shelter package or packages should depend to some extent on the number of shelter occupants. The data collected in the survey have therefore been reviewed to find the distribution of shelters by size.

4. Large numbers of shelters were found in Leicester and Hereford, other districts having very few shelters by comparison. As it was thought that there might be a significant difference in the size distribution between one area and another separate distributions were compiled for Leicester and Hereford and these are shown in the two upper histograms in the attached diagram.

5. It can be seen that the distributions are not very different from one another. Class intervals of 500 sq.ft. were used and the distributions are J-shaped the largest numbers of shelters having a floor area up to 500 sq.ft. However when the numbers in the first two classes are broken down into intervals of 100 sq.ft. it can be seen that there is a peak at between about 200 and 400 sq.ft.

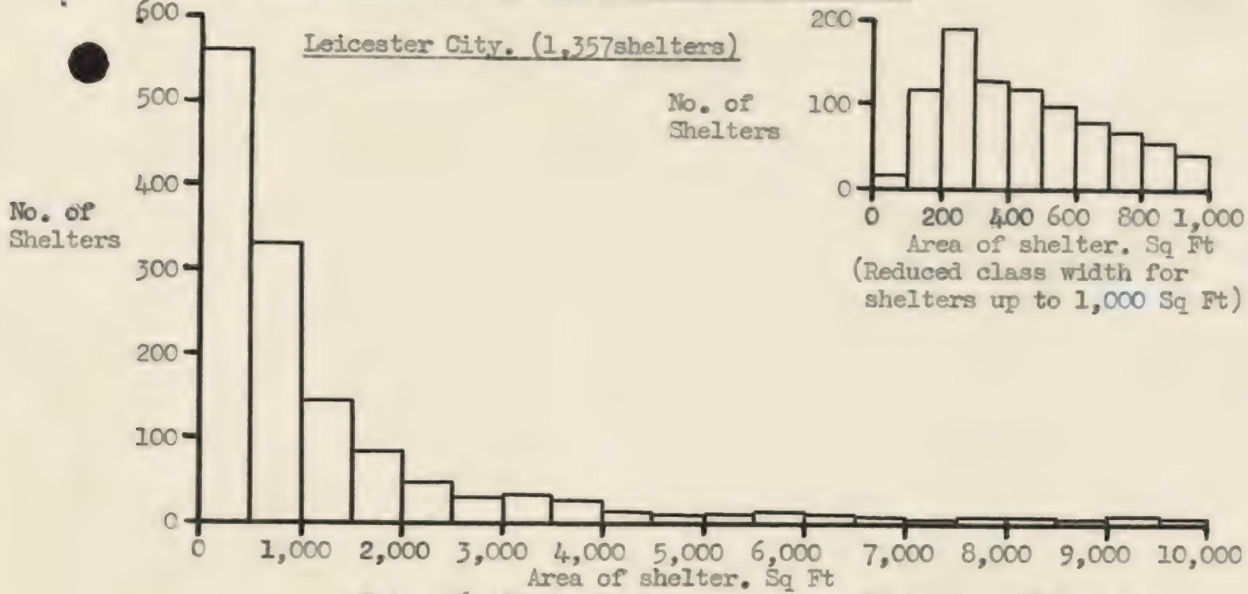
6. As the distributions for Leicester and Hereford are not significantly different the data for both have been combined together with that for other districts to give a single distribution. It can be seen that about one half of all shelters found in the survey have areas between 100 and 500 sq.ft. and three quarters between 100 and 1000 sq.ft. Above 1000 sq.ft. the distribution has a very long tail, occasional shelters having areas as great as about 50,000 sq.ft.

7. The allowance of space per person,and consequently the number of people to be accommodated in a shelter,will probably vary according to circumstances. It seems likely that assuming no bunks in shelters the floor space should not be less than about 15 sq.ft per person.

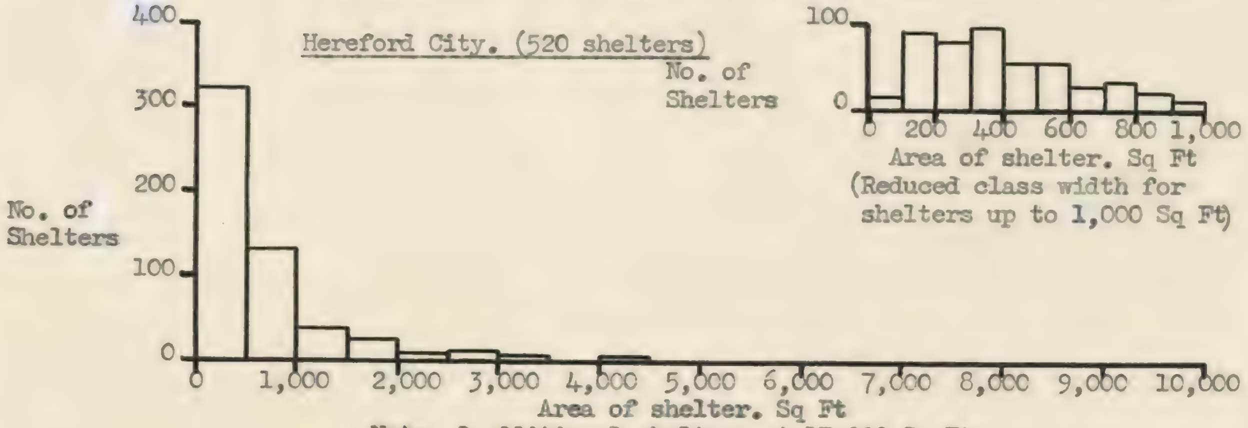
D. T. Jones

April 1966.

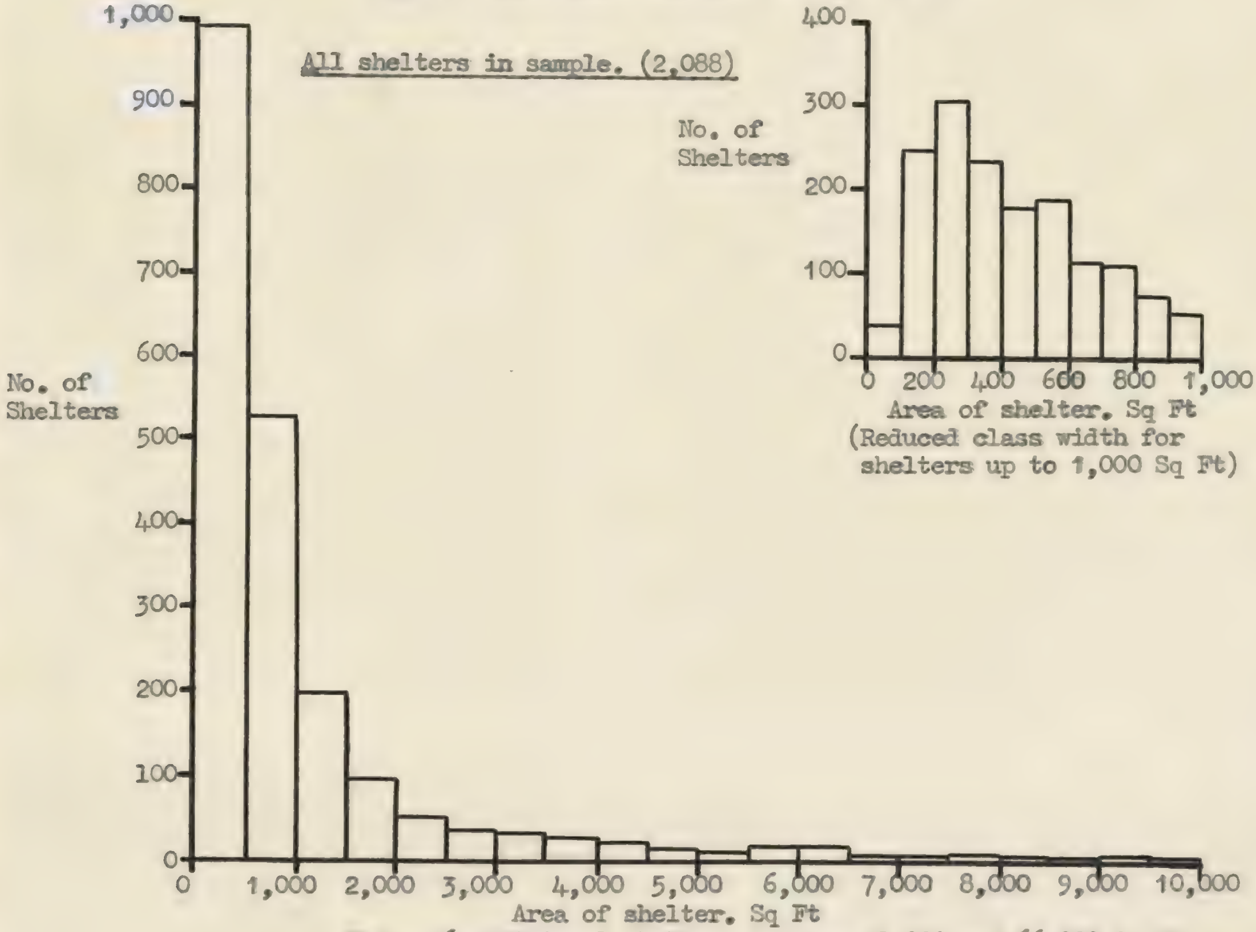
DISTRIBUTION OF BASEMENT SHELTER BY FLOOR AREA



Note: 26additional shelters between 10,000 and 66,000 Sq Ft



Note: 2 additional shelters at 17,000 Sq Ft



Note: 36 additional shelters between 10,000 and 66,000 Sq Ft

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MINISTRY OF HOME SECURITY

RESEARCH AND EXPERIMENTS DEPARTMENT

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STRUCTURAL DEFENCE, 1945

by

D.G. CHRISTOPHERSON, D.Phil.

Fellow of Magdalene College, Cambridge.

Formerly of the Research and Experiments Department, Ministry of Home Security

January, 1946.

R. C. 450

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MINISTRY OF HOME SECURITY

RESEARCH AND EXPERIMENTS DEPARTMENT

STRUCTURAL DEFENCE, 1945

by

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C_b damage – Uninhabitable and too seriously damaged to be repaired in wartime

C_a damage – Uninhabitable but capable of rapid repair

D damage – Habitable but badly needing repair.

Table 8.2 then gives results comparable with those in Table 8.1.

TABLE 8.2

DAMAGE AND CASUALTIES FOR HOUSES

Grade of damage	Average circle radius (ft.)	No. of houses studied	Casualty data							
			No.	Total number of casualties			Total No. of occupants	Percentage of casualties		
				K	S/I	L/I		K	K + S/I	K + S/I + L/I
A	77	206	191	76	63	20	323	23.5	42.6	48.8
B	115	172	146	7	29	22	257	2.7	14.0	22.6
C_b	156*	299	282	0	30	19	326	0	9.2	15.0
C_a	–	173	158	0	4	4	182	0	2.2	4.4
D	–	44	43	0	0	0	45	0	0	0

* This value is an underestimate owing to the restriction of the zone of investigation to a distance of 170 ft. from the explosion. C_a and D radii were not measureable for the same reason.

CHAPTER VIII

THE PROTECTION OF THE PUBLIC:- SHELTERS

8.1 General considerations in shelter provision

The problem of the protection of the public from an attack can clearly be tackled from two directions:-

(i) by removing people from areas subject to attack, and
(ii) by providing them with accommodation within which they will be reasonably safe, even in an area which suffers heavy bombardment.

Obviously the first solution, when practicable, is much to be preferred. There is no doubt that thousands of lives were saved during the war by evacuation. But the solution has only a limited application. The work of the country must go on, and the workers must not only congregate in large numbers during working hours, but must also live relatively near their work, that is to say, in or near those areas which will attract attack. When the production of the country is concentrated, as is largely the case, in a few areas, the task of the attacker is rendered much easier, and in the colossal amalgam of industry, transport and commerce which is represented by a city like London, he can drop bombs almost at random knowing that few will be, from his point of view, entirely wasted.

The situation therefore arises in which people must be protected against an attack directed not primarily against them, but against the essential life of the country. The attempt may be made to destroy the actual means of production, the factories, by blast or fragmentation, to dislocate transport by blocking roads and railways by the craters of delay-fuzed bombs, or to force the workers to leave their work by destroying, usually by the use of fire, the dwellings in which they live. Against all these agencies of attack protection must be provided, and, if this is done, it will be found that to a very large extent, the people have also been protected against an attack, if one should be launched, directed primarily against them.

In estimating the relative efficiency of various shelter types, we take account of these considerations by introducing an "occupancy" factor. Suppose that the vulnerable area for a person taking shelter is V_s and for a person not taking shelter is V_n. Then if p per cent of the people for whom the shelter was intended do in fact occupy (on the average over a number of raids) the mean vulnerable area for these people is -

$$p\,V_s + (1 - p)V_n$$

and it is this quantity rather than the actual vulnerable area V_s of the shelter itself which should be regarded as giving the measure of efficiency.

The numerical value of the percentage occupancy p depends of course on many factors such as the weight of attack, the state of public morale, etc. We are here interested only in relative values as between different types of shelter. The figures given below, for example are estimates of occupancy during a typical night raid during the period 1940-41[5]:-

Type of shelter	Percentage of population occupying shelter
Interior (Morrison or protected room type)	75 - 80
Exterior domestic shelter (Anderson or domestic surface type)	50
Small public shelter (surface communal or trench type)	30

It may be that in these cases the figures will also cover fairly well raids of the short-duration day type. If, however, we included the large public shelter, such as the deep tunnel shelters in London, the occupancy figure would be very high for a night raid, but very low (owing to inaccessibility) when the time of warning was short.

(ii) The Anderson shelter (Fig. 8.1)

The Anderson shelter is, of course, simply a very small covered trench shelter in which the earth is retained by a corrugated steel arch held in place by light R.S. sections. Very large numbers of these shelters have been used in Great Britain and there is considerable experience of their behaviour. This experience indicates that, as expected, in a properly constructed and covered shelter few casualties occur except when the shelter itself is seriously damaged. If, for example, we categorize damage as follows:-

Category		
A1	Shelter totally destroyed	"heavily damaged"
A2	Shelter very badly distorted	
A3	End sheets removed, and/or moderate distortion of arch	"slightly damaged"
A4	Minor damage including reduction of earth cover	

We can relate the number of casualties occurring with the type of damage. This has been done for a group of 700 Anderson shelters which were attacked by flying bombs exploding within 170 ft. It is necessary to distinguish between those shelters which had (as all of them should have had) a baffle consisting of a brick wall or earth bank opposite the door to prevent the entrance of fragments or debris, and those in which the entrance was unprotected.

TABLE 8.1

DAMAGE AND CASUALTIES FOR ANDERSON SHELTERS[6]

Grade of damage	** Average circle radius (ft.)	Number of shelters studied	Casualty data (Shelters with complete data)							
			No.	Total number of casualties			Total number of occupants	Percentage of casualties		
				K*	S/I*	L/I*		K	K + S/I	K+S/I+L/I
All shelters -										
A1	15	13	13	5	1	0	6	83.3	100	100
A2	24	14	12	3	6	2	19	15.8	47.4	58.0
A3	39	24	15	2	6	6	28	7.1	28.6	50.0
A4	66	71	57	1	5	5	71	1.4	8.5	15.5
Shelters without baffles -										
A1	15	10	10	5	1	0	6	83.3	100	100
A2	24	10	8	3	3	2	11	27.2	54.5	72.7
A3	39	16	10	2	4	5	18	11.1	33.3	61.1
A4	67	52	41	1	5	4	62	1.6	9.7	16.1
Shelters with baffles -										
A1	15	3	3	0	0	0	0	-	-	-
A2	24	4	4	0	3	0	8	0	37.5	37.5
A3	39	8	5	0	2	1	10	0	20.0	30.0
A4	72	19	16	0	0	1	9	0	0	11.1

* The casualty classification is as follows:- K - killed. S/I - Seriously injured and detained in hospital. L/I - Slightly injured - received medical attention but not detained in hospital.

** The "average circle" radius is defined as the distance such that the number of shelters undamaged within a circle of this radius is equal to the number damaged outside the circle. It corresponds closely to the "vulnerable area" but is easier to compute.

The vulnerable area, as defined in equation (8.1) can be readily computed from these results, if we replace the integral in that equation by an arithmetic summation of the areas of damage times the probability of injury in each area. Fixing attention on the totals of killed and seriously injured we find the following figures -

	Vulnerable area K + S/I
All shelters	2,830 sq.ft.
Shelters without baffles only	3,200 sq.ft.
Shelters with baffles only	1,720 sq.ft.

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Following the same procedure as before, we find, for killed and seriously injured taken together, the vulnerable area about 16,000 sq.ft. or more than nine times that for the properly protected Anderson shelter.

The flying bomb was of course a blast weapon, i.e. it always exploded on the surface without penetration. As such, it was equivalent to an H.C. bomb of charge-weight ratio 75 per cent and charge-weight (RDX/TNT) about 1,050 lb. and accordingly we may estimate the vulnerable area of the properly protected Anderson shelter as no more than 2,750 sq.ft. per ton of bombs of this type. But, as we remarked when considering trenches in general, any sub-surface shelter cannot readily be attacked by blast weapons; the main threat is from the delay-fuzed penetrating bomb.

Direct evidence as to the casualties produced by such bombs in Anderson shelters is scanty, due partly to the difficulty of identifying the bombs responsible for specific incidents in raids in which several sizes of bomb variously fuzed were used simultaneously, and partly to the fact that in the early part of the war the system for the collection of the required information was not fully developed, while more recently, the penetrating bomb has more and more been superseded by blast weapons. It is possible, however, to relate damage to the shelter directly with the crater size of the bomb causing the damage, and some results obtained in this way are shown in Fig. 8.2.** From this diagram we can see that the vulnerable area for "heavy damage" from penetrating bombs is about 1.6 times the crater area. The average crater area for (say 50 kg. bombs fuzed 1/40 sec. delay or longer is about 180 sq.ft. (weighting the areas for various types of soil in the proportions in which they have in fact occurred); so that we may estimate the vulnerable area (killed or seriously injured) as approximately 290 sq.ft. for this type of bomb,* giving the vulnerable area per ton 5,800 sq.ft.

* In Reference 7 Professor S. Zuckerman found that the vulnerable area for the occupants of a group of small shelters (mostly Andersons) was only 270 sq.ft. but some of his data may have involved non-penetrating bombs. In the same paper, he shows that the corresponding figure for people in houses is 1,430 sq.ft. about 5-6 times as great. In a later paper R.E.N.182 "A comparison of the number of casualties caused by German bombs of different sizes", Professor Zuckerman found that the vulnerable area against the 50 kg. for persons in Anderson shelters was no more than 126 sq.ft. compared with 810 sq.ft. for persons in houses. Note that although these figures are much reduced, no doubt as a consequence of the increased use of instantaneous fuzes in the raids studied, the ratio between the two remains about the same as before.

** Fig. 8.2 not reproduced.

Other larger types of trench shelter will clearly be more vulnerable due to the increased risk of a direct hit, and to the fact that many of the lining materials used were less capable of distortion without rupture than the corrugated steel of the Anderson.

(iii) The surface shelter (Figs. 8.3 and 8.4)

The public surface shelter as originally designed was intended for use in streets, factories, etc., where trenches were not appropriate, due to the unfavourable nature of the ground or other causes. It was thought before the war that the main risk to be contended was that from fragmentation, and the prime requirement was therefore to make the walls fragment-proof. In fact, the principal risk arises from the collapse of a shelter as a result of blast or earthshock, and if these risks are adequately met, the fragmentation risk will be negligible.

The standard of protection aimed at was also much lower than that subsequently achieved. The earliest surface shelters were designed to be proof against blast and fragmentation from a 500 lb. bomb (TNT filled) at 50 ft. and so they were. But it was afterwards found to be possible to reduce this distance to 15 ft. i.e. to nearly the standard of protection afforded by the Anderson shelter. Owing to its larger plan area, it was necessary for the surface shelter to be proof against a near-miss even closer than that required to damage an Anderson, in order to give a comparable degree of protection.

At this distance the shelter had to be proof -

(a) against the blast and fragmentation from a surface burst-bomb;

(b) against the earthshock from a delay-fuzed bomb, and in addition,

(c) the velocity with which it was displaced by earthshock had to be below the critical velocity for injury laid down in paragraph 8.3.

We have already in Chapter VII discussed in detail the problem of the design of wall panels against blast. A shelter wall does not of course differ from any other in this respect so it is not necessary to recapitulate the calculations given in that chapter.

The conclusion reached is that walls of thickness $13\frac{1}{2}$ in. for brick or 12 in. for concrete reinforced in each case against earthshock in the manner shown in Figs. 8.3 and 8.4 are satisfactory from the point of blast. It is also obvious that the performance will be improved if the shelter is allowed to slide freely on its foundation, thus absorbing some part of the blast energy. We have also noted that these walls are virtually proof against fragmentation.

We must, however, contemplate a form of failure which has not been covered by the fundamental investigations in the earlier chapters - the risk that the shelter may disintegrate either as a result of the original earthshock or more probably as a result of the impact which occurs when the shelter strikes the ground again after being projected through the air.

The earlier unreinforced surface shelters were particularly liable to collapse in this way, and a large part of the full-scale experimental work carried out by R. & E. Department in the early part of the war was directed towards determining a design which would not collapse under severe earthshock conditions, and also to devising means whereby the original unreinforced types could be strengthened up to the required standard.

A considerable number of full-scale tests were carried out with this end in view, a typical layout being that shown in Fig. 8.5. The designers were, of course, throughout handicapped by the necessity for extreme economy in the use of steel, which was, at that time, in very short supply, and in considering the designs which are shown as Fig. 8.3 and Fig. 8.4 it must be remembered that these forms were considered the best that could be done <u>with the amount of steel available.</u>

The technique of design for these conditions had to a great extent to be improvised. The remarks made in chapter VII with regard to the treatment of a "one-life" structure, and with regard to the consideration of ultimate strength rather than elastic limit, of course holds good in this context. But it is not immediately apparent how estimates can be made of the forces disintegrating the shelter, and thus of the strength necessary to hold it together. A means of approach to this problem of the measurement of the disintegrating forces was found in cine-photography. A series of photographs were taken at a moderately high speed (say 200 frames per second), of the process of disintegration of an unreinforced shelter under the specified conditions. The velocities with which the various parts scattered could then be measured from the film, and hence an estimate of the disintegrating impulses could be obtained.

One such photograph shown in Fig. 8.5a illustrates the way in which an ordinary rectangular brick shelter with reinforced concrete slab roof and floor breaks up and is demolished by a 500 lb. bomb buried 12 ft. 6 in. at 15 ft. from the shelter wall horizontally*. This photograph and others like it illustrate clearly enough what the task of the designer is -

(a) the separation of floor, roof and walls, as a result of "knock-on" effect must be prevented,

(b) the shelter must not be allowed to "fold up", i.e. to assume the form of an elongated parallelogram.

It is found that the forces necessary to prevent the separation of the various elements of the shelter are not large. A very small percentage of steel reinforcement (as little as 0.06 per cent by volume has been used), if carried continuously from the floor through the walls and into the roof, is sufficient to keep the whole structure together. When a very low percentage reinforcement is used, however, it is usual to provide cross-walls at intervals along the shelter length, as shown in Fig. 8.4, with a view to stiffening the section, and preventing "folding up". The floor, which was omitted in some of the earlier types, is almost a necessity for the same reason. Photograph 8.7, taken under the same conditions as 8.5a, illustrates the success of these measures.

The comparatively low percentage reinforcement necessary to keep the shelter together can be easily demonstrated by a calculation as follows:-

Suppose that an unreinforced shelter is tested under the specified conditions, and the maximum relative velocity of roof and walls is measured photographically and found to be 5 ft./sec. in a shelter of area 30 ft. x 8 ft. having walls 1 ft thick[8]. Then the kinetic energy of the roof, assumed 5 in. thick, and of density 144 lb./cu.ft. is

$$\frac{60 \times 25}{64} \quad \text{ft. lb./sq.ft.}$$

In this plan there are 72 ft. of wall supporting an area 240 sq.ft., so that the kinetic energy of the roof per foot run of wall is -

$$\frac{60 \times 25 \times 240}{64 \times 72} \quad \text{ft.lb.}$$

The work done in extending the reinforcement is necessarily less than this, since much of the energy will go into elastic vibrations of the roof, etc. Then, if there are A sq.in. of reinforcing bars per foot run of wall, having yield stress 50,000 lb./sq.in. the extension of the reinforcement

* In the actual tests 250 kg. (550 lb.) German S.C. bombs were used.

is necessarily less than δ ft. given by -

$$A\,\delta\,50{,}000 = \frac{60 \times 25 \times 240}{64 \times 72}$$

For 0.06 per cent reinforcement in a 1 ft. thick wall A = 0.06 x 1.44 so -

$$= \frac{60 \times 25 \times 240}{64 \times 72 \times 50{,}000 \times 0.06 \times 1.44} \text{ ft.} = .22 \text{ in. (approx.)}$$

The separation of roof and wall cannot therefore be more than ¼ in. and will probably be much less. In practice it is quite probable that not even a crack would appear there.

This calculation is an example of the use that can be made in design on the one hand of structures which are specifically intended to fail, and, in failing, to give information about the forces causing failure, and on the other hand of the cinematographic technique of velocity measurement, which has been widely used in many connexions and which, as applied to the problem of earthshock movements and velocities, requires only relatively simple equipment. The photographic method also, of course, gives the information necessary to ensure that requirement (c) is met, - that the velocities imparted to personnel in the shelter are not such as to cause injury, regardless of whether the shelter is damaged or not. Walley's paper[8] indicates that the velocities imparted to the shelters are lower than the threshold injurious velocities quoted in paragraph 8.3, but not by much. Clearly it is useless to endeavour to strengthen the shelter further with a view to ensuring that it successfully resists demolition under even more severe conditions, unless at the same time we make it much heavier, so as to prevent the velocity of projection rising above this threshold value. We shall have occasion to consider this point in more detail, when we come to the consideration of "bomb-resisting shelters" (Chapter IX).

One further possibility must be taken into account; the surface shelter must necessarily be capable of supporting a considerable mass of debris on its roof. Moreover, since it is commonly constructed on roads and among buildings, it must be capable of sustaining the impact of heavy masses of masonry, or perhaps large pieces of concrete projected into the roof at moderate velocities. In Chapter IV we have stated that the velocities likely to be achieved by such large missiles as a result of the explosion of a buried bomb are not likely to exceed about 70 ft./sec.

Not much experimental work is available as to the effects of the impact of relatively slow moving missiles on concrete slabs*. All the work quoted in Chapter VII on impact on concrete beams refers to "beams" which were supported at the ends only and failed by simple fracture at the centre. The problem of the slab which under some conditions will fail by "punching" is essentially different. In R.C. 188, however, Gimpel and Marshall reported a valuable series of experiments, although their slabs, being reinforced with expanded metal, were not typical of shelter roof design. The slabs tested were all similar of 3 ft. square and 2½ in. thick, simply supported on a free span of 2 ft. 6 in. with 0.7 per cent reinforcement, and having an ultimate static strength under a central load of about 3 tons. A weight of 7.9 lb. was dropped from various heights on this slab, and it was found the energy required to hole the slab, when the load was distributed over an area 3 in. square was in excess of 200 ft./lb. When a cast iron ball was used as striker so that the area loaded was smaller, the energy required was about half as much. The damage caused was quite local, suggesting that for impacts at moderate velocity the method of support of the slab is not a matter of the first importance.

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* If the bomb explodes immediately below the road surface the velocities will be much higher, but the concrete will be broken up into much smaller pieces.

Applying the dimensional theory outlined in Chapter VI we find that a rigid mass of 63 lb. falling with velocity 40 ft./sec. on to a slab 5 in. thick, similarly reinforced, would just fail to hole it, provided that the area of contact was not less than 6 in. square. In the rough and ready demolitions carried out at the end of the war, a weight of 22 cwt. was dropped 4-5 ft. on to such roofs, and only succeeded in making a hole by repeated impacts on the same point. On this basis it may therefore be expected that the occasions on which shelter roofs of the type shown in Figs. 8.3 and 4, will be holed by debris will be very rare. Experience has confirmed this conclusion. Of shelters built experimentally on concrete roads with reinforced concrete roofs 5-6 in. thick only one was holed by debris in a test under the specified conditions. Cases in which shelter roofs have been holed by debris in actual raids are so rare as to be almost non-existent.

All the causes of injury enumerated in paragraph 8.3 have now been considered, except (d) fragmentation injury and (f) direct blast injury.

In Chapter III we pointed out that walls of the thickness shown in Figs. 8.3 and 8.4 would seldom, if ever, be penetrated by fragments from bombs bursting outside. At the standard 15 ft. distance from the 500 lb. bomb, we showed in Chapter III that the "mass fragmentation" effect would powerfully reinforce the blast effect, but in Chapter VII we argued that these walls would be adequate to resist both acting together. The risk from fragments entering by way of doorways, must of course be combated by providing a suitable "baffle" wall, covering the entrance (or possibly, a suitable fragment-proof door). The complexity of the baffling necessary will vary according to the design of shelter used, but in general it should be such that no fragment can enter the inhabited part of the shelter without at least one ricochet.

A direct measure of the vulnerability of the normal brick surface shelters is not easy since no one standard design was built in large numbers. The shelters actually used were for the most part strengthened versions of the original unreinforced brick shelter, and a number of different systems of strengthening were employed. For example, the exterior of the shelter might be covered by a steel mesh, held in position by an additional $4\frac{1}{2}$ in. brick skin, and by additional concrete on the roof. Alternatively, a similar plan could be adopted in the interior (Fig. 8.7) but in so doing the shelter was rendered considerably safer than the reinforced type designed ab initio as in Figs. 8.3 and 8.4. The walls were 18 in. thick as opposed to $13\frac{1}{2}$ in. thick in the reinforced design, and the roof is also thicker. These increases in weight will improve the performance substantially both against blast and probably also against earthshock.

The evidence of field results is that such a strengthened shelter will not be damaged seriously by blast from a flying bomb at distances greater than about 35 ft. This test is almost certainly appreciably more severe than that imposed by the 250 kg. S.C. bomb (filled TNT) at 15 ft. and accordingly the shelter is somewhat safer than the standard laid down. The reinforced brick shelter Fig. 8.3 is probably only just up to the required standard, although the reinforced concrete is also slightly better. The vulnerable area for the strengthened type could not be estimated with any degree of confidence from the comparatively small amount of field data available, but what there is suggests a value of about 2,700 sq.ft. against the flying bomb. When attacked by a blast weapon the shelter is thus markedly inferior to the Anderson type. When the attack is by penetrating bombs, however, there is little difference between the two.

The public surface shelter is, however, particularly vulnerable to one form of attack which has not materialized in an acute form in this war. There would be no difficulty about designing a bomb of weight about 10-15 lb., charge-weight perhaps 2-3 lb., which would be capable of penetrating the roof of thickness 8 in. or less and exploding inside. The casualties from the internal explosion of such a bomb would be heavy, and even allowing for the fact that owing to fuze defects some bombs would detonate either before penetrating the roof or after passing the floor, the average vulnerable area is likely to be perhaps 100 sq. ft. or more. The vulnerable area per ton aircraft load is then

about 20,000 sq.ft. - more than four times that for the large blast weapon. Such a weapon will be relatively less effective against the smaller shelter types, such as the Anderson, owing to the small area which they present to direct hits.

In addition to the public surface shelters, illustrated in Figs. 8.3 and 8.4 several other types of brick surface shelter were in use. The small domestic type of shelter illustrated in Fig. 8.8 were intended to replace the Anderson shelter when the ground was unsuitable for subsurface construction. Some of the earlier types had arched or corbelled roofs, with a view to economy in steel, but this construction has obvious weaknesses under earthshock, and the usual flat roofs tied by reinforcing to the walls are much to be preferred.

The "communal" type illustrated in Fig. 8.9 consisted in effect of an amalgam of small "domestic" shelters constructed together. The weight of the whole was naturally greater than that of the less heavily partitioned public shelter, and for this reason it was probably slightly safer, particularly against the "small bomb" attack envisaged above. In general, however, all these surface brick shelters, when strengthened up to the 1941 standard could be considered to provide approximately comparable protection.

(iv) The "indoor" shelters

The use of strengthened basements or other strengthened rooms as shelters was widespread early in the war. Provided that the buildings chosen for this purpose were suitable, and that the strengthening was adequate, these shelters afforded a fair measure of security, particularly against blast weapons. In general the requirements were:-

(1) the strutting should be such that the roof was capable of supporting the entire debris load of the building above if it completely collapsed, and moreover should have enough lateral stability to eliminate the possibility of collapse when the roof was loaded unsymmetrically by the collapse of one part only of the building.

(2) The strutting should be so placed that, in the event of the destruction of one or more walls of the shelters by earthshock from a near-miss, it would not be damaged to an extent which would render it incapable of supporting the debris load resulting from the collapse of upper floors. This could be done by placing the main struts at some distance from the exterior walls - never against them. Other minor modifications, such as the bricking up of area lights, etc., were also made, and where the shelter was large in area, it was subdivided by partition walls comparable in strength with surface shelter walls in order to reduce the lethal area of a bomb of medium calibre penetrating into the shelter.

The degree of protection afforded by such a shelter was to a very large extent governed by the nature of the building in which the shelter was placed. In a modern steel-framed building the risk in a basement shelter was very small - probably not more than 1/10th as great as that in the Anderson, if the improved occupancy is allowed for, and by bricking up windows, etc., an equally good shelter could be constructed on the second or third storey of such a building.* Moreover, the weight of debris falling on the roof of the shelter consisting, in a framed building simply of demolished partition walls, etc., can usually be easily carried by the frame without additonal strutting, provided that the roof of the shelter is sufficiently substantial to prevent local collapse. Much the same is true, though the risks were slightly greater, in a reinforced concrete framed building. In any future plan for the protection of the public the utilization of such buildings, which are likely to be more numerous in the future than they have been in the past, may be a prime consideration.

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* For a discussion of steel and reinforced concrete framed buildings cf. Chapter X.

In multi-storey load-bearing buildings of the "monumental" type protection is fairly good particularly against bombs of small or moderate calibre. When the attack is by large bombs serious calamities are likely to occur. The weight of debris falling on a shelter if a large part of the building above is demolished is very great, and the time taken to extract the occupants of the shelter if they have survived, is proportionately long. Although such shelters may be of value in providing "quick" protection for persons working in these buildings they cannot be regarded as satisfactory as a standard type of public shelter.

At the other end of the scale we come to the problem of the provision of a suitable indoor shelter which could be used in the millions of small two-storey houses, terraced, detached or semi-detached, which exist in the country. Few of these houses have cellars or basements and even where these exist, they do not provide any satisfactory protection since the occupants cannot be situated very far from the external walls, and these are as liable to collapse by earthshock as a trench shelter constructed of a non-ductile material. Such a collapse of an external wall is likely to cause injuries at close quarters even if strutting prevents the collapse of the house as a whole.

On the other hand, it was clear by the end of 1940 that an indoor shelter for the small house was urgently desirable. The occupancy statistics (paragraph 8.4) alone argued strongly in its favour, and indeed the idea had been mooted at a much earlier date. The objections which were then foreseen were as follows:-

(a) the shelter could not be such as would decrease substantially the living accommodation in the house, which was, as a rule, already fully utilized. This objection was fatal to most plans for "strutted rooms", etc;

(b) the shelter must be capable of sustaining the debris load resulting from the complete collapse of the house; but access to it, - and escape from it - must be as easy as possible. It was greatly feared that if persons were trapped in such shelters the onset of fire would put an end to the usefulness of the shelter.

It was to meet these objections that the well-known "Morrison" table shelter was introduced; and since this shelter has been, on the whole, the most successful in practice in this war, we shall devote some attention to it.

(v) The Morrison table shelter

Fig. 8.10 shows the design adopted. The details were to some extent determined by the material which happened to be available for the purpose at the time.

The plan area 6 ft. x $4\frac{1}{2}$ ft., while giving adequate room for 2 persons to sleep (4-5 persons were accommodated in a "2-tier" shelter) was not much larger than that of the ordinary table which the shelter was intended to replace. The steel-mesh curtains forming the sides could readily be removed and provided means of access from any direction. It was found that the fears of the pre-war advisers on the subject of fire in debris were not justified. Where a house was so completely demolished that the occupants of the Morrison were left with no route of escape the lack of air supply at all points, except those exposed on the surface of the heap of debris, combined no doubt with the quantity of stone dust suspended in the atmosphere, made it almost impossible for fire to maintain itself in the ruin. Indeed, such demolished houses acted as effective fire-breaks in incendiary raids. True, houses which were only partially demolished or severely damaged were particularly susceptible to fire; but in such houses the occupants of a Morrison usually had at least one route of escape open.

It may be that in the extremely intense fire "tempests" caused by the heavy R.A.F. raids against German cities late in the war, this would no longer have been true. It has been stated that in the heavily built up zone in the centre of a city, when almost every building was on fire, escape by way of the streets became impossible, and casualties due to fire among persons in otherwise undamaged shelters were very high. This, of course, suggests that any type of shelters should be built in an open space and not among a concentration of inflammable buildings. Under the conditions in which the Morrison shelter was most widely used, however, in small houses in areas where the building density was comparatively low, it may be that no fire tempest so severe as to prevent escape from the affected area could have been induced.

The height of the shelter was made low enough to be below window sill level in the average room, and the position in which the shelter was placed was selected to be as far as possible out of range of flying glass. By the methods of Chapter III we can predict that ordinary 9 in. brick walls of a two-storey house were very nearly proof against fragmentation, especially from the higher charge-weight ratio weapons, and that even a $4\frac{1}{2}$ in. brick partition offers a substantial measure of protection.

The main structural requirements were laid down from a detailed consideration of the loads which would be applied to the shelter when the house containing it was demolished.

The shelter had to be capable of sustaining -

(1) A dead load of 320 lb./sq. ft. laid over the whole area of its "roof" or top.

(2) The weight of an area of floor 14 ft. x 6 ft. 6 in. x 20 lb./sq.ft. (the maximum floor area which can strike the shelter when placed in a room in which the supported span is 14 ft.), i.e. the total of the dead load and superimposed load on timber floors of normal domestic occupancy, falling flat on the shelter from a height of 6 ft.

(3) The same area of floor, loaded similarly, hinged about one wall, and falling from the same height to strike the edge of the shelter in an oblique direction.

(4) A horizontal load 160 lb./sq.ft. applied on any side (to resist the horizontal thrust from the debris in a collapsed house).

A full discussion of the design of a shelter to meet these specifications will be found in R.C. 204 "The design and testing of the table (Morrison) indoor shelter". The procedure may be summarized as follows:-

(a) The frame is designed in accordance with the procedure of Chapter VII so that the members are capable of absorbing in plastic bending without excessive displacement the energy imparted to them by the impacts described.

(b) The other parts, e.g. the top plate and the side weld-mesh curtains, and the bottom "mattress" are designed to develop the full strength of the frame.

Actually, the 22 gauge (.03125") plate would be sufficient for the purpose, but in fact a $\frac{1}{8}$ in. steel was used since a supply of the thicker plate was more readily available. It was the original intention to secure the steel laths of the mattress by bending over the bottom angles and securing to the side panel studs. In order to facilitate bundling of the laths for transport this plan was abandoned in favour of attachment by hooks and springs. Experience, however, showed that although the latter plan was reasonably satisfactory, the mattress was inclined to break away from the frame under severe conditions, and it might have been worth while to retain the original design.

The various designs evolved by R. & E. Department, together with a number submitted for consideration by independent designers, were tested "ad hoc" under the conditions described above. Fig. 8.11 shows a test being carried out under conditions (3). Small deformations of the shelter under tests (2) and (3) were considered acceptable, provided they were not so large that the occupants would have been endangered. In the actual tests, the rectangular block of masonry of weight 336 lb. dropped centrally on the shelter was substituted for the floor described in (2) and constituted on the whole a more severe test.

The only risk which remains to be considered is that arising from the shelter and the occupants being thrown about by blast or earthshock. This risk can never be entirely eliminated, particularly in a light shelter; but the Morrison design aimed to reduce it in several ways.

In the first place, the shelter was always provided with a floor of interwoven steel strips, which ensured that if the shelter was lifted, the occupants went with it. Without this floor there would be a serious risk that the occupants would be injured by quite a small displacement of the shelter. Secondly, the mesh sides ensured that there would always be very complete and rapid diffraction of blast inside and outside the shelter, so that no large velocity would be imparted to it by blast. Finally, the horizontal ties at floor level, in addition to contributing greatly to the stiffness and stability of the shelter, went far to ensure that the "legs" of the table would not be driven through the floor on which the shelter stood, with resulting crushing of the occupants between floor and roof.

Turning now to direct field experience of the behaviour of Morrison shelters, we find that, as far as delay-fuzed penetrating weapons are concerned, this is almost entirely lacking, since the shelter did not come into common use until the period (after the middle of 1941) when the enemy confined himself almost entirely to blast weapons. We have however some reliable information, again collected during the flying bomb attack. We can relate the four variables -

(i) casualties to occupants

(ii) damage to shelter

(iii) damage to house in which shelter was placed

(iv) distance from bomb

For this purpose we can define the following categories of shelter damage:-

M1 Shelter destroyed (minimum distance between mattress and top reduced to less than 12 in. as a result of buckling of the top plate, or distortion of the frame)

M2 Heavy damage (minimum clearance between mattress and top more than 12 in. but maximum deflection of top more than 9 in.)

M3 Slight damage (deflections less than 9 in.)

Table 8.3 gives the relation between the type of damage suffered by the shelter and the condition of the house (classified as notes to Table 8.2) in which the shelter was placed.

TABLE 8.3

FATE OF MORRISON SHELTERS IN DAMAGED HOUSES

Category of house damage	Number of shelters damaged to the category					
	Total	M1	M2	M3	Undamaged	Unknown *
A	53	1	1	11	26	14
B	48	0	0	2	46	0
Cb	61	0	0	0	61	0

* If the shelter was not occupied, information about its behaviour was sometimes unobtainable.

It will be seen that out of 39 shelters of known behaviour exposed in houses which were to all intents and purposes totally demolished, only two were seriously damaged, while of 109 shelters in houses seriously damaged, all survived.

This extremely small number of shelters heavily damaged makes it impossible to determine from practical experience what is likely to happen to the occupants of such shelters. Of the five occupants of the two shelters referred to above, only one was injured. Table 8.4 below corresponds in all particulars to Table 8.1 for the Anderson shelter.

TABLE 8.4

DAMAGE AND CASUALTIES FOR MORRISON SHELTERS

Grade of damage	Average circle radius (ft.)	Casualty data									
		No. of shelters studied	Shelters with complete data								
			Number	Total number of casualties			Total No. of occupants	Percentage of casualties		
				K	S/I	L/I		K	K + S/I	K + S/I + L/I
M1	-	1	1	0	0	0	2	-	-	-
M2	-	1	1	0	1	0	3	-	-	-
M3	51	13	12	1	4	4	29	3.4	17.2	31.4

The best that can be done with these rather fragmentary results is to group all the damaged shelters together. We can then find that for persons in Morrison shelters within 51 ft. of the point of burst the proportion of casualties will be as follows:-

No. exposed to risk	No. killed	K + S/I	K + S/I + L/I
34	1	6	10
100%	3%	17.6%	29.4%

The persons further away from the burst are practically safe. The vulnerable area for killed and seriously injured which results, is 1,440 sq. ft. - an even lower figure than that already quoted for the Anderson shelter.

It will be realised, of course, that the more effective a shelter is the less reliable will be the numerical information relating to its performance. As the number of casualties occurring in the shelter decreases, the variations in the number due to chance factors necessarily form a large proportion of the whole. On the other hand, as we noted earlier in this chapter, it would be a cardinal error to attempt to increase the number by investigating, for the purpose of vulnerable area determination, only those incidents in which casualties had occurred. All incidents in which the shelter is "exposed to risk" under the assigned conditions must be investigated, or, at any rate, if a selection is made, the basis of it must be quite arbitrary, and must not be related in any way to the performance of the shelter.

Although, for the reason given above, we have no direct information as to the effect of penetrating bombs against the Morrison shelter we may anticipate that the vulnerable area per ton of bombs will not be greater and may well be less than was the case with the blast weapon. The house damage per ton of bombs, will certainly be less, for example, from 4-250 kg. S.C. or 2-500 kg. S.C. delay-fuzed than from a 1-ton blast bomb, and accordingly we may expect some reduction in the vulnerable area for Morrison shelters.

The small 10-15 lb. bomb, which is a menace to the surface shelter, is also dangerous here. Such a bomb, exploding in the same room as the Morrison would certainly expose the occupants to a severe risk. But the problem of fuzing such a bomb to explode between (say) 15 ft. and 25 ft. below a roof of variable weight, after passing through an upper floor containing a variable amount of furniture of variable resistance, would be very difficult, and it would not be surprising if not more than 1/5 of all bombs striking on the required area exploded at the right level. If, as may well be the case, even these bombs kill or seriously injure only half the shelter occupants the vulnerable area per ton will be found to be no more than that for the large blast weapon.

On the whole, therefore, the Morrison shelter can be regarded as the best (though not incomparably the best) solution to the problem of the shelter of the occupant of the small house. This is especially true when "occupancy" figure is taken in to account. It is probable that the shelter could also be used in the lighter types of three-storey buildings, though the time of rescue of the occupants, in cases where the shelter is buried, is likely to increase sharply with the weight of debris covering it.

(vi) Tunnel shelters

The physical data on which the design of tunnel shelters must be based has already been given in earlier chapters. In Chapter II we described the propagation of blast in tunnels, and in Chapter IV we gave the conditions under which spalling or collapse of the tunnelled rock could be expected. All that is necessary here is to refer to the question of vulnerable area.

We must here differentiate sharply between the effect when the bomb explodes in or very nearly in the tunnel, and the effect when it is sufficiently far away to cause nothing more than spalling of the rock. In the latter case, a local block may occur; but provided that the shelter is furnished with an adequate number of exits so that no large number of people can be trapped by a single fall, casualties will only occur in the limited area in which the fall has taken place. On the other hand, when the bomb penetrates into the tunnel casualties are likely to be numerous, not so much as a result of direct blast effects, as in consequence of the very large "windage" effects which will cause injury both as a result of people being violently displaced themselves, and as a result of the violent displacement of loose material of all kinds. It is therefore essential that in a tunnel shelter which is at a depth at which there is even the barest possibility of penetration, the shelter should be intersected either by numerous blast traps of the kind described in paragraph 2.7 or by extremely strong and heavy blast walls, or both, the number of persons within any one subdivision being strictly limited.

Tunnel shelters have not been used much in the United Kingdom (with the exception of the London tube railways, to which we shall refer again in Chapter XIII), and for an example of a tunnel system in practice, we must return to the German constructed V-weapon sites in the Pas de Calais mentioned in Chapter IV. As we stated, a tunnel system for which the overhead cover above the crown of the tunnel arch was 95 ft., was attacked by 12,000 lb. M.C. bombs fuzed a delay long enough to ensure that the bomb came to rest before exploding. Actual casualty figures for this attack are not available, but if we assume that all persons in the portions of the tunnel completely blocked or very heavily spalled by debris were casualties, we find a vulnerable area of 6,750 sq.ft. per bomb, or 1,260 sq.ft. per ton aircraft load. One of the bombs however "blew through" into the tunnels which consisted of a rectangular system without blast traps or subdivisions of any kind. This bomb would almost certainly have caused many additional blast casualties so that the total vulnerable area per ton may have been in excess of 2,000 sq.ft. per ton - about the same, against this type of bomb, as the small shelters we have described earlier in the chapter. Of course, tunnels at such a depth would be virtually safe against bombs of smaller calibre, such as would commonly be used in attacks on towns. Indeed, in considering the safety of the smaller shelters it is not necessary even to consider if the protection against specially heavy weapons is adequate. The necessity to do so in considering tunnel systems arises from the following considerations:-

(1) A tunnel system constructed to accommodate only a few people is an absurdity. If the overhead cover is to be adequate a large part of the cost will arise from the construction of entrances, shafts, etc., and these, once constructed, could probably without much addition be used to serve a tunnel system of much larger dimensions.

(2) A tunnel system will therefore be constructed only when a large number of people (say 5,000 - 30,000) are to be accommodated.

(3) The plan area of the system so constructed will be considerable: not less than about 1 acre per 2,000 persons, and thus with modern bombing technique it will be possible to be sure of hitting it with a limited number of aircraft, even if the bombs required are so large that each aircraft carries only one bomb.

(4) With a population scattered over the whole town in a large number of diminutive shelters it is useless, from the point of view of causing casualties, to attempt to aim at any selected point; but if a large number of persons are collected in a single shelter, it may very well be considered worth while, as part of a policy directed against public morale, to attack this shelter and to select that type of bomb which is necessary for the purpose.

Thus in designing small shelters, one has only to reckon with those weapons which are likely to be used for attacking any targets which happen to be in the district considered; but when a really large shelter is contemplated every weapon, including those which would be specifically selected to attack the shelter itself, must be taken into account. By collecting large numbers of people together in a tunnel one creates a target where none existed before.

A large tunnel system can therefore only be quite satisfactory if placed at a depth at which there is no possibility of perforation. What depth will in the future be necessary to meet this requirement is, of necessity, a matter for speculation. If we consider only weapons now produced *, it seems that about 160 ft. of chalk or equivalent depths in other rocks should suffice. But if a means is found to delay detonation in a weapon of a high-velocity rocket type, the equations of Chapter I show that this figure may become quite inadequate.

It should be noted that these considerations do not apply to the accommodation of small numbers of persons in existing tunnel systems provided that the cover is reasonably adequate. Where very large underground works exist at depths less than that required for complete safety it may even be possible to utilize them to accommodate a reasonable number of people provided that on the one hand the population density in plan is not large enough to present an attractive target to the enemy, and on the other hand that the tunnels are provided with such substantial sub-divisions that the effects of an internal explosion are confined within a reasonably small area.

8.6 The "calamity" risk

It will be realized that the remarks above in reference to tunnel systems applies, mutatis mutandis, to all large shelters. Not only is a large shelter more likely to be deliberately attacked, but, in addition, when successfully attacked, the large number of casualties resulting simultaneously constitutes a much more serious problem than an equal number distributed in a number of small incidents over a period of time. Rescue and medical services, for example, are very much better able to cope with a continuous trickle of casualties than with an equal number arriving together; and it is widely believed, though as far as the writer is aware, it cannot be proved, that such calamitous incidents have an adverse effect on morale.

For these reasons the British policy has been throughout this war to eliminate as far as possible the "calamity" risk by never concentrating a large number of people in a single shelter except when an extremely high degree of security could be offered. A large shelter, to be as safe as a small one, has to be a great deal safer.

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* Written in June, 1945.

APPENDIX

THE DISTRIBUTION OF EXPENDITURE[9]

In the preceding pages, we have reviewed briefly the essential structural requirements in a shelter. We have shown that in many cases, advantage can be taken of existing buildings to provide protection better than that which could be provided ab initio for the same expenditure. Evidently then, the form which shelter provision should take in a given locality should be governed in many cases by the local conditions, by the nature of the existing buildings, by the local availability of materials, etc. Nevertheless, it is useful to consider briefly the quite general problem of the way in which a fixed expenditure, available for protection of a given area - say a large industrial town - should be distributed.

Suppose that the area under consideration can be divided into a number of localities of area $S_1\ S_2\ S_3$ ..... sq. miles, in which the expected density of attack is $N_1\ N_2\ N_3$ ..... ton/sq. mile, and suppose that the protection provided in these areas is such that the mean vulnerable area per ton for the inhabitants, (when allowance has been made for occupancy) is $A_1\ A_2\ A_3$. The chance that any one person will become a casualty is then $N_1\ A_1, N_2\ A_2, N_3\ A_3$ respectively, provided that these fractions are small compared with unity and, if the population density is $D_1\ D_2\ D_3$, etc., the total number of casualties is -

$$N_1A_1D_1S_1 + N_2A_2D_2S_2 + N_3A_3D_3S_3 \qquad \ldots\ldots\ldots\ldots (8.6)$$

Now let us suppose that the relation between vulnerable area and cost per head of population is -

$$C = f\ (A)\ ^{*}$$

and that the values of C corresponding to A_1, A_2, A_3, are C_1, C_2, C_3.

Then we have the total expenditure C given by

$$D_1S_1C_1 + D_2S_2C_2 + D_3S_3C_3 + \cdot\ \cdot\ \cdot = C \qquad \ldots\ldots\ldots (8.7)$$

Various "policies" are of course possible. For example, we might decide that a constant expenditure per head of the population should be made throughout ($A_1 = A_2 = A_3$, $C_1 = C_2 = C_3$). In equity, it might be argued that everyone ought to run as nearly as possible an equal risk ($N_1A_1 = N_2A_2 = N_3A_3$) or taking a somewhat more hard-headed view, that the objective is to minimize the total casualties given by (8.6) above.

If we accept the "equal risk" theory, we have of course -

$$A_1 = \frac{k}{N_1} \qquad A_2 = \frac{k}{N_2} \qquad \text{etc.} \qquad \ldots\ldots\ldots\ldots (8.8)$$

and k is determined by substituting C_1, C_2, C_3 in (8.6)

If we accept the "minimum total casualties" therefore, we can proceed as follows:-

Suppose that we make a small increase in the expenditure in zone (1) ΔC_1, at the expense of zone (2) then we have

$$D_1S_1\,\Delta C_1 + D_2S_2\,\Delta C_2 = 0 \qquad \ldots\ldots\ldots\ldots (8.9)$$

But $$\Delta C_1 = \left(\frac{\delta f}{\delta A}\right)_1 (\delta A)_1 + \Delta C_2 = \left(\frac{\delta f}{\delta A}\right)_2 (\delta A)_2 \qquad \ldots\ldots\ldots\ldots (8.10)$$

So thus $$D_1S_1 \left(\frac{\delta f}{\delta A}\right)_1 (\delta A)_1 + D_2S_2 \left(\frac{\delta f}{\delta A}\right)_2 (\delta A)_2 = 0 \qquad \ldots\ldots\ldots\ldots (8.11)$$

---

* It is here that the argument lacks generality. This function is not single valued but depends on the local circumstances.

Since the total number of casualties (8.6) is an absolute minimum, the effect of this small change in expenditure must be zero and

$$N_1D_1S_1\ (\delta A)_1 + N_2D_2S_2\ (\delta A)_2 = 0 \qquad \text{.........}\ (8.12)$$

Eliminating between (8.11) and (8.12) we find

$$\frac{1}{N_1}\left(\frac{\delta C}{\delta A}\right)_1 = \frac{1}{N_2}\left(\frac{\delta C}{\delta A}\right)_2 \qquad \text{.........}\ (8.13)$$

and by making similar small changes in C_3, etc., we find that this equation can be extended to all indices and since on our hypothesis C is a function of A only, we can write -

$$N_1\left(\frac{\delta A}{\delta C}\right)_1 = N_2\left(\frac{\delta A}{\delta C}\right)_2 = N_3\left(\frac{\delta A}{\delta C}\right)_3 \text{ etc. .....}\ (8.14)$$

We note that if the equation relating cost and vulnerable area is of the form

$$A = A_0C^{-KC} \qquad \text{.........}\ (8.15)$$

the equation (8.7) obtained on the "equal risk" hypothesis is identical with equation (8.14) obtained on the "minimum casualties" hypothesis. In certain areas which do not lend themselves readily to any one type of protection, the equation may well be approximately true, but very often it will be found impossible to improve protection by increased expenditure, at the rate required by (8.15), so that if it is required to retain the "minimum casualties" hypothesis, there is nothing for it but to admit that the inhabitants of the most heavily attacked area must accept a greater risk*.

The defence of an essential command post, or military fortification, offers a parallel problem. Here the alternatives are to have one immensely strong erection, having an exceedingly small vulnerable area, or to have several duplicate posts of less strength. Suppose the vulnerable area of the single unit is A_1, the density of attack being D_1. Then the probability of destruction is $1 - e^{-A_1D_1}$. In the alternative case, N similar units each have vulnerable area A_N and the probability that they will all be knocked out is:- $(1 - e^{-A_ND_1})^N$.

The cost of the single unit is C_1, and for equal expenditure, the multiple units of course cost $C_N = \frac{C_1}{N}$. Thus duplication is undesirable provided that -

$$1 - e^{-A_1D_1} < \left\{1 - e^{-A_ND_1}\right\}^{C_1/C_2} \qquad \text{..........}\ (8.16)$$

Now if A_1D_1 is small, equation (8.16) can be written in the form -

$$A_1D_1 < (A_ND_1)^{C_1/C_2}$$

or, for the case when duplication only is contemplated

$$A_1D_1 < \sqrt{A_2D_1}$$

Thus, for example when $A_1D_1 = \frac{1}{100}$, duplication is worth while unless the single structure is ten times safer than each of the duplicates.

If A_1D_1 is large (> 1) we proceed as follows:-

Duplication is undesirable if -

$$1 - e^{-A_1D_1} < 1 - 2e^{-A_2D_1} + e^{-2A_2D_1}$$

$$e^{-A_1D_1} > 2e^{-A_2D_1} - e^{-2A_2D_1}$$

---

* This can be very easily demonstrated if we take occupancy into account. Suppose that a Morrison shelter has a vulnerable area $\frac{1}{8}$ that of an unprotected house, and that its "occupancy" is 80 per cent. Then in an area attacked three times as heavily, a perfect shelter (one of vulnerable area zero) would have to have an occupancy of 95 per cent - an almost impossibly high figure - to give an equal risk).

Now since A_2D_1 is still larger, the last term can be neglected, and we have duplication undesirable if

$$e^{A_1D_1} \qquad \tfrac{1}{2}e^{A_2D_1}$$

$$A_1D_1 \qquad A_2D_1 + \log \tfrac{1}{2}$$

Thus the larger A_1D_1 becomes the smaller must be the ratio A_2/A_1 in order that duplication may be worth while. If the risk to the single installation is high (A_1D_1 1) the duplicates have to be almost as safe as the original in order to offer any advantage. Duplication of defences is an excellent means of eliminating the risk of an unlikely calamity, but it is almost useless for buttressing a forlorn hope.

Of course, in the example we have quoted there are many other factors to be taken into account; for example, the persons manning the fortification may have their own opinion as to how strong it should be; but there are many installations, such as communication cables, power supply systems, etc. in which the whole basis of the problem is summed up in the few lines above.

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3 Burns, B. Delisle, and Zuckerman, S. "The wounding power of small bomb and shell fragments" R. & E. Department R.C.350, October, 1942.

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5 See also R. & E. Department "A study of the safety/cost relation in different types of dwelling" R.E.N.177, October, 1942.

6 This and the following tables are taken from R. & E. Department "The relative effectiveness of various types of shelters against flying bomb attacks" R.E.N.464, January, 1945.

7 Zuckerman, S. "The field survey of air raid casualties" R. & E. Department R.C.270, November, 1941.

8 See for example:- Walley, F. "Movement of shelters due to earthshock" R. & E. Department R.C.287, January, 1942. In this paper it is shown that the maximum velocity imparted to the standard surface shelter as a whole, from a 250 kg. bomb at 15 ft. horizontally from the shelter wall, and 12 ft. 6 in. deep is about 10 ft.-sec. somewhat less than that imparted to the ground at the point in the absence of any surface load.

9 The argument here given will be found in more detail in R. & E. Department "Protective measures in new dwellings: an approach to the policy of expenditure" R.C.330A, June, 1942.

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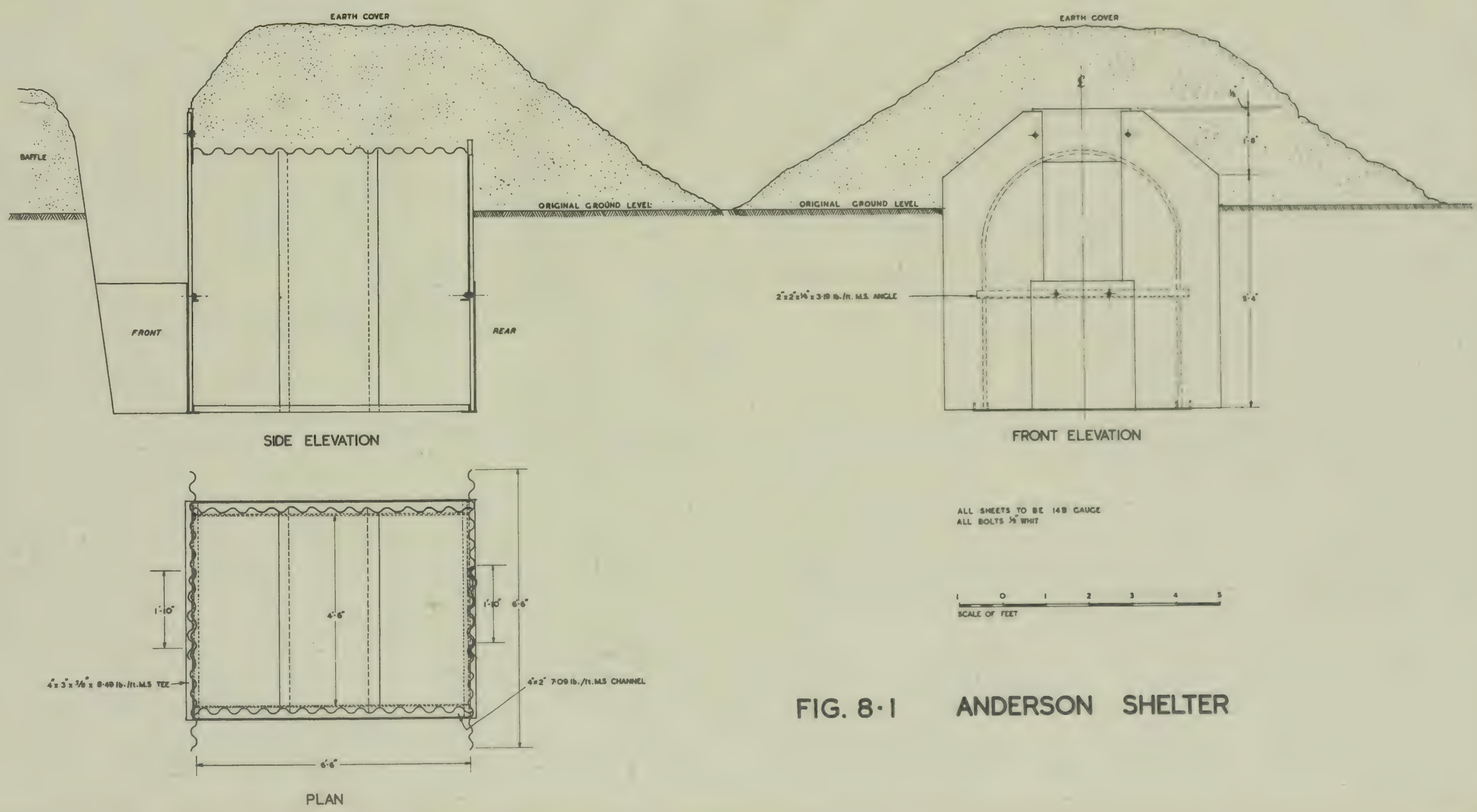
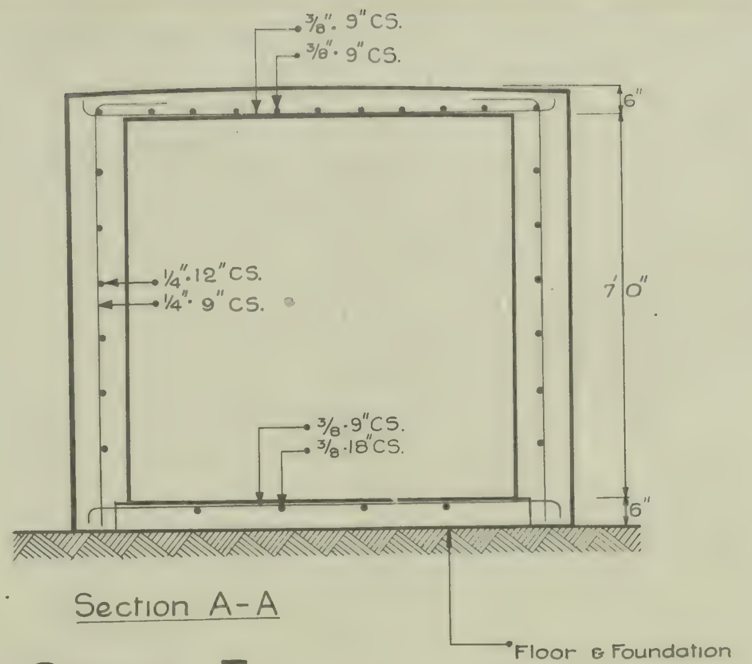
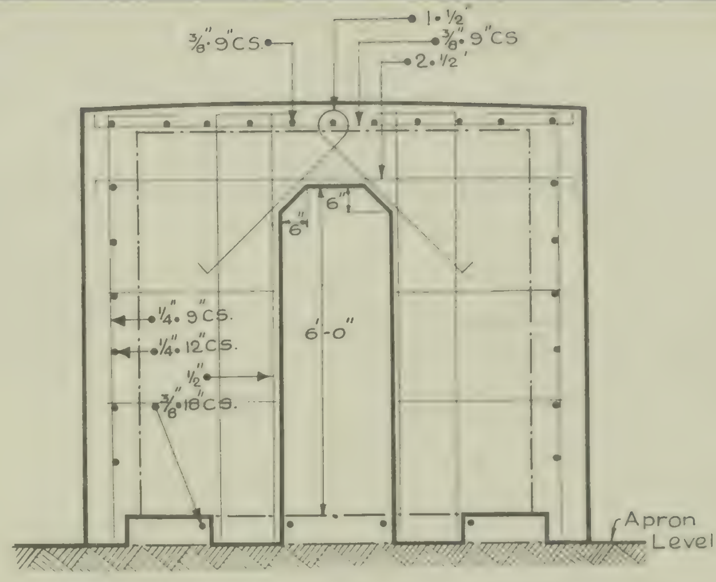


FIG. 8·1 ANDERSON SHELTER



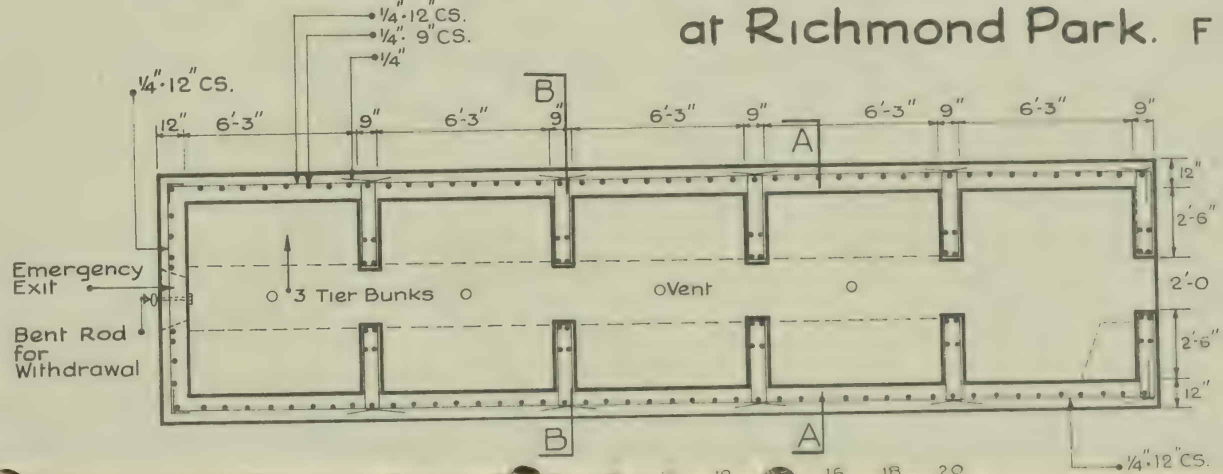
Section A-A



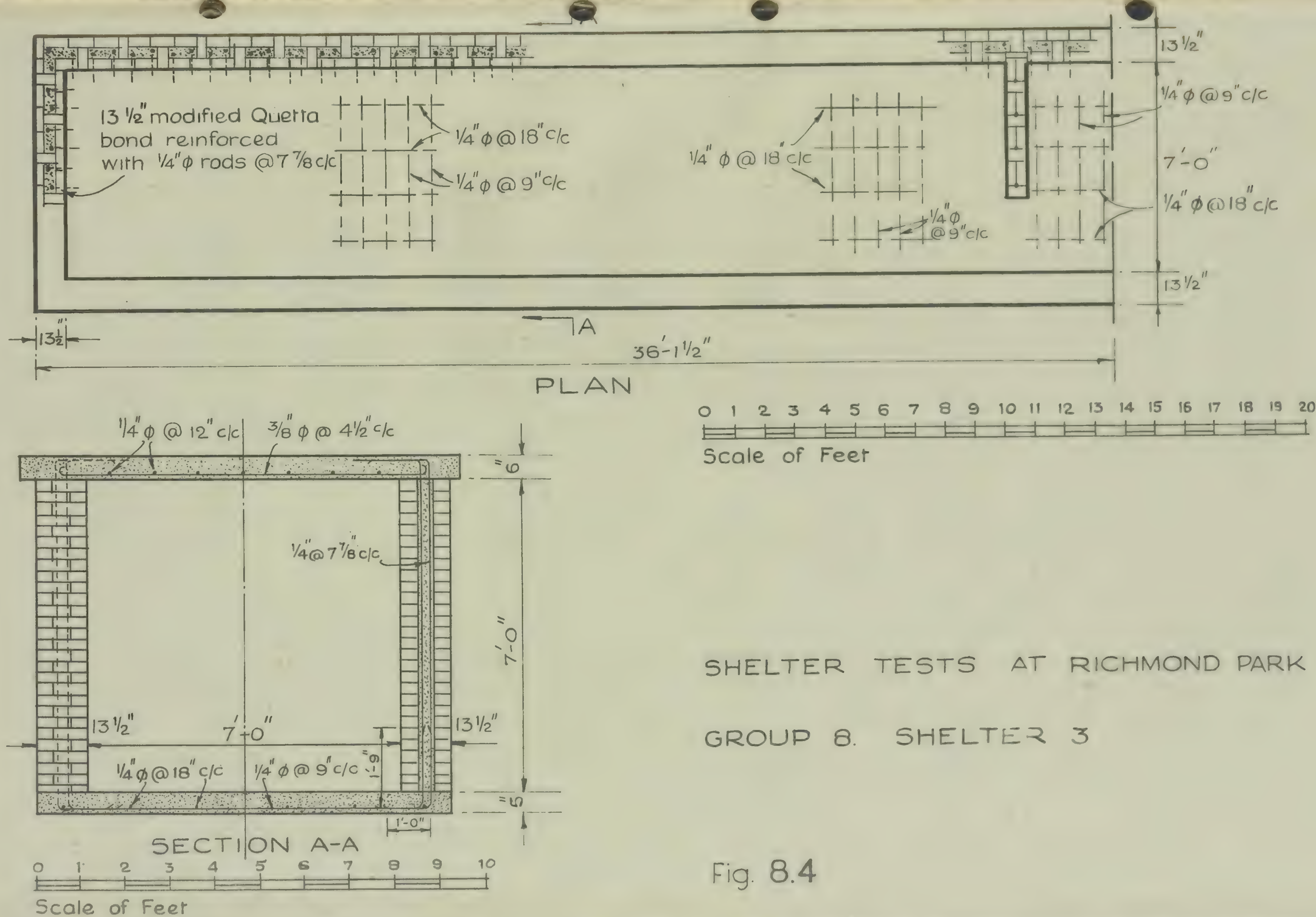
Section B-B

Group 5

Shelter Nº 2-Reinforced Concrete Shelter Test at Richmond Park. FIG. 8.3.



Plan

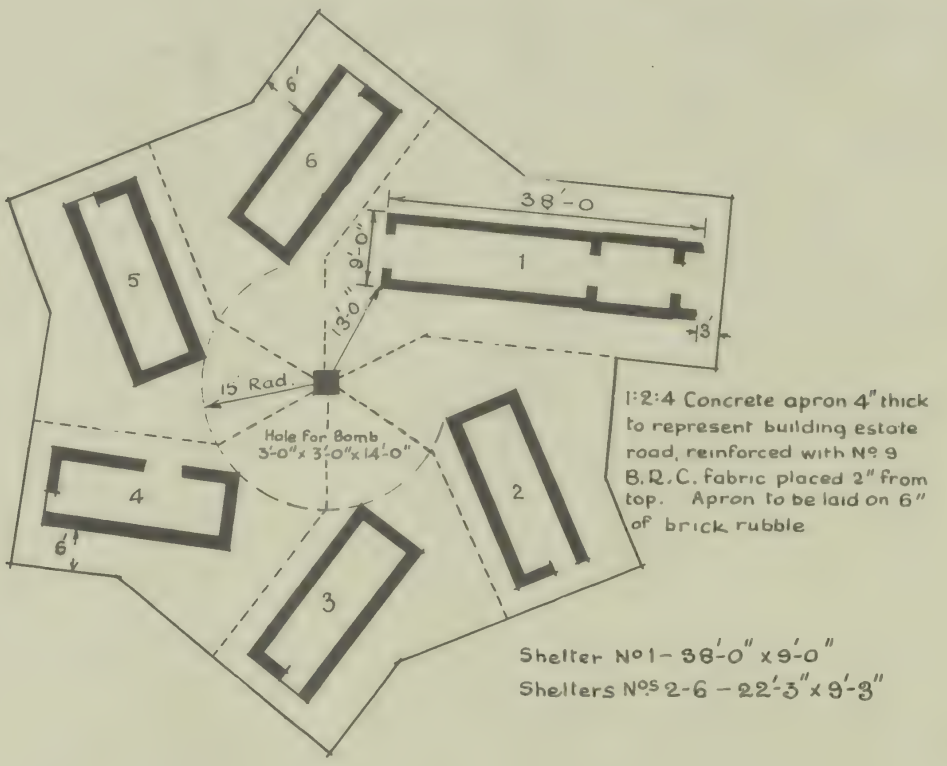


SHELTER TESTS AT RICHMOND PARK

GROUP 8. SHELTER 3

Fig. 8.4

Shelter Nº 1 - Reinforced concrete.
Shelter Nº 2 - Reinforced brick skin.
Shelter Nº 3 - Normal type.
Shelter Nº 4 - R.C. inner skin with base plates.
Shelter Nº 5 - do: with R.C footings under wall.
Shelter Nº 6 - R.C. inner skin with floor.



GROUP 1.
PROPOSED SHELTER TEST
TO BE HELD AT RICHMOND PARK

FIG. 8.5.

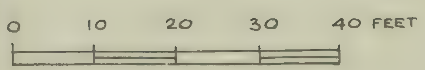
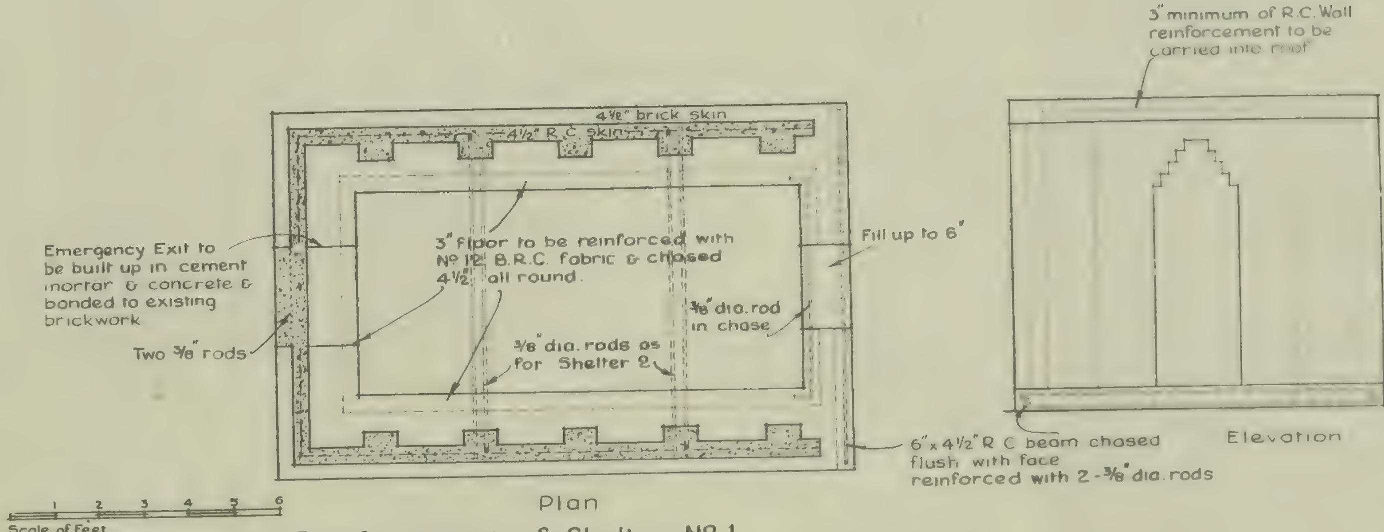


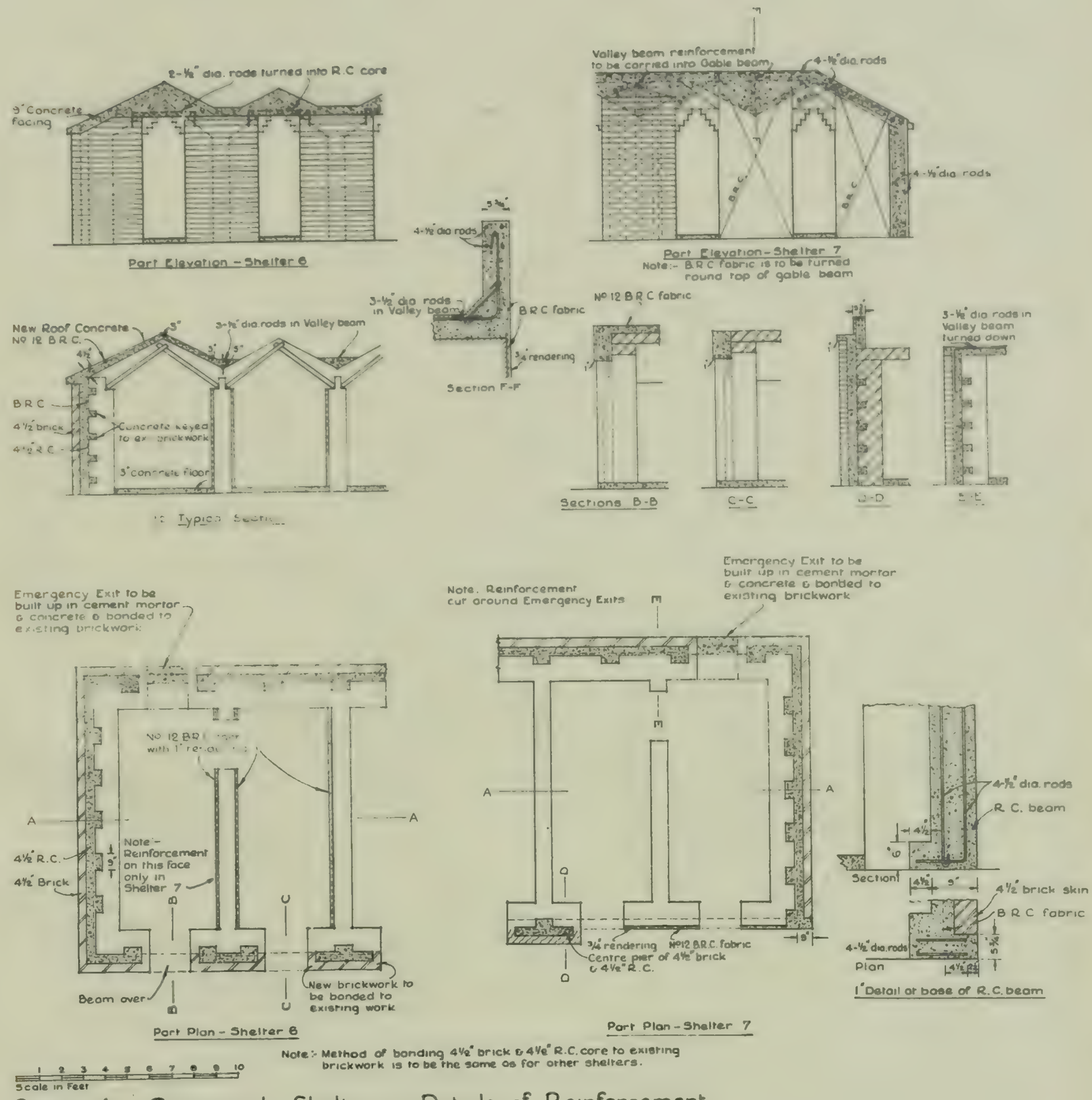
Fig.8.6 Effect of ground-shock from a buried bomb on a group of unreinforced brick surface shelters. The roof of the shelter on the left is seen separated from the walls while that next to it has its back broken by the movement. (Paragraph 8 & 31)

Fig.8.7 Effect of ground-shock on a group of reinforced brick surface shelters and one reinforced concrete shelter (on extreme left). Note how shelters are thrown into the air without fracture. (Paragraph 8)



Group 4. Reinforcement of Shelter No 1

FIG. 8-8



Group 4. Communal Shelters — Details of Reinforcement.

FIG. 8.9

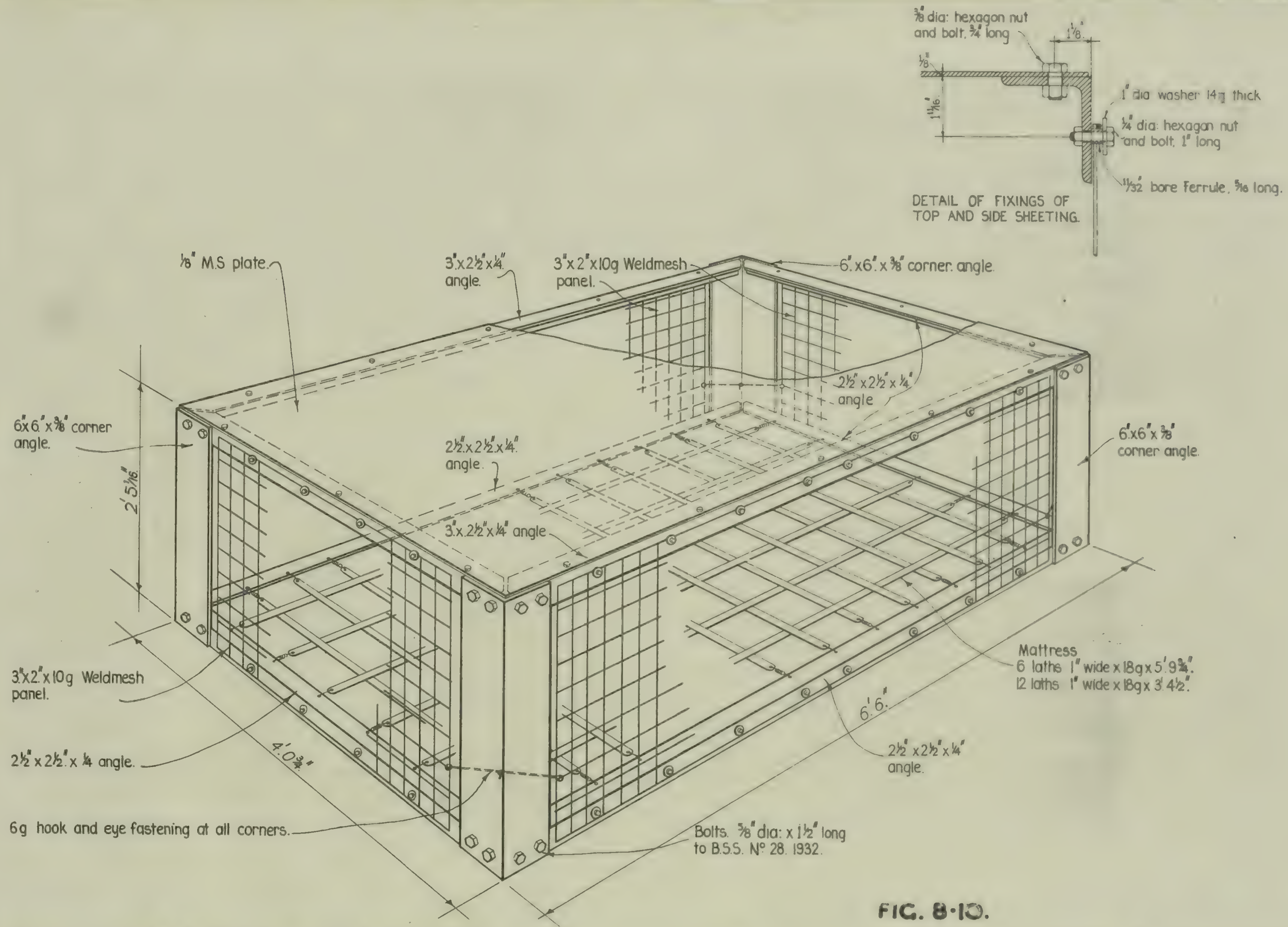


FIG. 8·10.

FINAL DESIGN OF INDOOR TABLE SHELTER.

Photo 1.

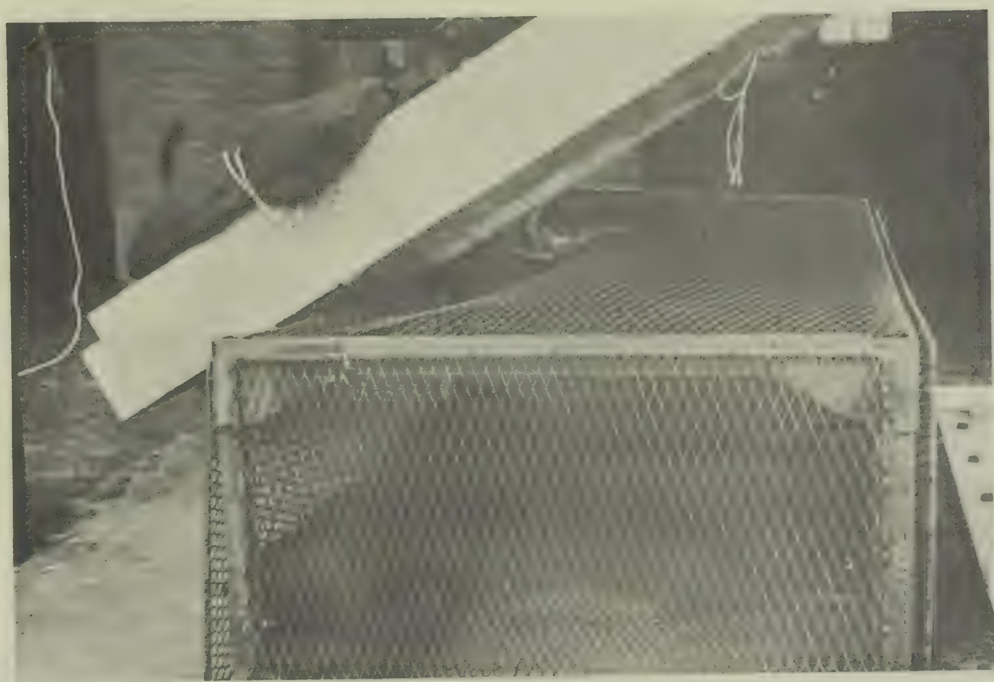


Photo 3.

Fig. 8.11 Falling floor impact test on indoor shelter.

CHAPTER IX

"BOMB-PROOF" SHELTERS AND FORTIFICATIONS

9.1 The meaning of "bomb-proof" and "bomb-resisting"

Ten years ago the word "bomb-proof" was self-explanatory. A building was "bomb-proof" if it could not be seriously damaged by any bomb capable of being carried in an existing aircraft. Even then, the requirements for a "bomb-proof" shelter were onerous, and necessitated extremely heavy construction, but they were within the bounds of possibility, provided that only a moderate amount of "bomb-proof" accommodation was required within the building.

At the beginning of the war, it was realized however, that a shelter, designed to be proof against the largest bombs then in service or under development, would require an expenditure of labour and material so large that it could only be justified in very exceptional circumstances. A few such "1939 bomb-proof" shelters or "fortresses" were constructed, mostly for housing an operational command headquarters of the fighting services, and this standard of construction became known as "fortress protection". Judged by 1945 standards, it is not completely bomb-proof, and indeed it is very doubtful if there exist anywhere, constructions capable of resisting the largest penetrating bombs now in use.*

Between the small shelters described in the last chapter, and the "fortresses" there was a very wide gap, both in safety and expenditure, and to bridge it a third standard of protection was introduced - the so-called "bomb-resisting" shelter designed to be safe against bombs up to weight 500 lb. This standard necessitated a roof about 6 ft. thick in reinforced concrete (as opposed to the 10-12 ft. roof of the fortress) the other dimensions - walls, and floors, - being in proportion. Although not many shelters of the bomb-resisting type were built in Great Britain, we have considerable direct evidence of its behaviour, a very similar standard having been widely used by our opponents. Many fortifications of the "Atlantic wall" were constructed approximately to this standard; and also a number of the formidable "Bunker" shelters, erected in the cities of western Germany, when it became clear that an effective reply was being made to the earlier German attacks on British industry. Naturally, a good deal of experimental work was done in this country, in order to develop means of attacking the Atlantic wall and the Bunker shelters were often hit during our large-scale industrial raids.

Finally, a reference must be made to the last attempt made by the Germans to attain truly "bomb-proof" construction - in the submarine pens on the Atlantic coast, and on the "large sites", the huge concrete erections in the Pas de Calais which were intended to provide safe bases from which various "V" weapons could be aimed at London. When planned, these structures were undoubtedly believed to be practically bomb-proof (their roof thickness was over 16 ft.). The air campaign by which they were defeated forms not the least interesting narrative of the war.

For the present purpose, we need make no distinction between shelters and fortifications. The latter are simply shelters with a special purpose which may modify their form, for example, by necessitating an embrasure, which somewhat decreases the protection afforded, but in general the principles of design will be the same regardless of the purpose for which the shelter is intended.

Furthermore, whereas in dealing with small shelters, we had at our disposal a number of totally different types of protection involving different materials used in different ways, in the present chapter we shall deal almost exclusively with one material - reinforced concrete - and the general form of the protection offered will not vary much. We shall find as before that both surface and sub-surface shelters are possible in various conditions and that a wide range of geometrical shapes can be considered. In all types, however, we must provide a roof capable of resisting perforation, walls capable of resisting near-misses, whether in air or in earth, and a floor to resist the earth-shock from a more or less remote burst. Very occasionally, we may consider the use of armour plate for a special purpose, but the introduction of an entirely new type of "bomb-resisting" shelter on an entirely new principle (as the Morrison was introduced in the middle of the war) seems most unlikely.

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* We exclude a number of very deep tunnels, mines, etc., which are not constructions in this sense.

9.2 Methods of attack - direct hit and near-miss

Obviously any structure is liable to receive a direct hit or a near-miss. The larger the plan area of this target the more important relatively will be the former. In the very small shelters described in the preceding chapter we were able to give a very fair measure of protection without attempting to provide any defence whatever against a direct hit from any but the very smallest bombs. Our whole aim was to reduce the area in which a near-miss could inflict serious damage. At the other extreme, in the expanses of the submarine pens, often many acres in extent, the risk of serious damage by a near-miss was practically trivial, and the whole purpose of the designer was first to provide a roof which would prevent perforations, and secondly, if this was impossible, to subdivide the interior in such a way that the area of damage caused by a bomb exploding inside was as far as possible restricted.

The bombs required for an attack on a heavy concrete structure differ according to whether the primary aim is to effect damage by direct hit or by near-miss. The near-miss attack requires an "M.C." bomb of charge-weight ratio about 50 per cent, which will probably, though not certainly, break up or detonate prematurely in the event of a direct hit. Two or three special types of bombs can be used for a "direct hit" attack; in general the charge-weight ratio of each is below 50 per cent and so, if a near-miss is scored the earth-shock or blast damage will be less than would be the case with the M.C. type. Accordingly the attacker must make up his mind beforehand whether his primary aim is to score direct hits or near-misses, and must select his bombs appropriately, knowing that if by chance his bombs score in the other category he will achieve less than maximum damage.

In practice, his choice is often influenced by the fact that his target consists not only of a number of heavy concrete structures but also of a complex system associated with them. In fortifications, for example, there are likely to be trench systems for local defence, cables for power and communications, roads or railways for supply purposes and so on. All these targets are best attacked by M.C. bombs, and for this reason the attacker will endeavour to retain these bombs - the near-miss type - wherever possible. A useful though inexact rule is that where the minimum weight of the bomb necessary to perforate the roof exceeds that of the bomb whose crater diameter (delay-fuzed) equals the width of the structure (the minimum plan dimension) then the attack should be by near-miss.

It follows that there is a certain limit beyond which it is useless to strengthen a small surface or sub-surface shelter.* Suppose its diameter is 30 ft. and that its floor is not more than 20 ft. below the surface, then a near-miss by an M.C. bomb of weight 4,000 lb. making a crater 60 ft. across will blow it out of the ground and will almost certainly put its occupants out of action. A shelter of this size cannot therefore be protected against 4,000 lb. bombs, and thus to provide it with a roof more than about 12 ft. thick, with a view to resisting bombs of this size or larger is practically useless. It will only prove useful if by some mischance the enemy elects to attack by direct hit. Of course, a shelter of the dimensions given is a most uneconomical proposition. A roof of this thickness can seldom be justified unless it provides a considerable protected space.

We have now to consider in detail the five main causes of damage to heavy concrete installations:-

(i) Direct hit, with instantaneous fuze: explosion in contact with roof.

(ii) Direct hit, with delay fuze: penetration or perforation followed by explosion.

(iii) Near miss, with instantaneous fuze: explosion near or in contact with walls above ground level.

(iv) Near miss, with delay fuze: explosion near or in contact with walls below ground level.

(v) Near miss, with delay fuze: explosion below shelter near or in contact with floor.

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* Assumed to be built on penetrable soil. On hard rock very great strength is possible in a small shelter.

We have already in Chapter I dealt at some length with the question of penetration, and in Chapter IV we have given some consideration to the effect of near explosions in earth. Some account must now be given of the effect of contact and very near explosions in air, and we must give further attention to contact explosions below the surface under conditions of confinement.

9.3 Contact explosions in air

Earlier in this book it has usually been possible to describe the effects observed simply in terms of the weight of the charge, and its position relative to the target. We can add definition to this latter phrase by referring always to the position of the centre of mass of the explosive. When we come to the study of contact explosions, however, it is no longer possible to leave out of account the effect of the shape of the charge, and as every student of demolition technique knows, the "closeness of contact", or absence of the most tenuous layer of air between charge and target has an important effect in increasing damage*.

For our present purpose, however, we are assuming that the attack is by projectiles, whether air-borne or not, which are of a quite unsuitable shape for establishing geometrically close contact with the plane surfaces of a fortification. We can, therefore, assume that the attacker does not in general enjoy the benefits of a real contact shot,** and in what follows we assume that contact is never closer than might be obtained by placing the charge against the surface without any special precautions.

In practice we are interested chiefly in a cylindrical charge of length about three to four times its diameter, either lying on the target with its axis parallel to the surface (the "sideways-on") or standing normal to it, with one end in contact (the "nose-on" position). For the most part we shall be interested in cased-charges, of medium or low charge-weight ratio, though we have little or no evidence that case weight is a matter of importance, when contact charges are under consideration.

The experimental evidence on this subject is not as complete as one could wish. A few generalizations, derived for the most part from small-scale experiments, may first be quoted.

(i) Light reinforcement does not have much influence in the size of the surface crater formed by a contact charge, but reinforcement near the rear face, particularly if in the form of a close mesh, may have an important effect in reducing scabbing.[1]

(ii) The crater volume varies approximately inversely as the square root of the concrete crushing strength. The tendency is for the depth of the crater to vary more than the diameter as the crushing strength varies[2]. There does not seem to be any very substantial correlation between the total thickness scabbed and the crushing strength[3] provided that the latter falls within reasonable limits (say 2,000-7,000 lb./sq.in.)

(iii) The crater made in a slab only just thick enough to resist the explosion is substantially smaller than that in a thicker slab.[3] This somewhat curious result might perhaps be used as a starting point in the further investigation of the mechanism of crater formation.

In Table 9.1 we give the results of a few full-scale and small-scale tests. These results are not complete; they do not, for example, enable us to say what is the minimum scabbing plate or rear mesh of reinforcing which will produce the effects described. However, they do suggest the following conclusion:- A mesh of mild steel reinforcement of the order of 0.5-1 per cent by volume, concentrated near the inner face will retain the shattered concrete in the scab from a sideways-on

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* Except in the one important case - that of the "shaped" Monroe charge - which, as we describe below, works best with a specified "offset" or space between charge and target.

** Some small bombs have been constructed with plastic explosives which are supposed to flatten themselves into close contact on striking the target. Some infantry anti-tank weapons are of this type, but it has not been used on any appreciable scale for aircraft bombs or shells.

contact explosion and will not bulge outwards by more than about 1/7 span (an acceptable maximum) provided that the thickness of concrete (inches) exceeds nine times the cube root of the charge-weight (lb.) (TNT or amatol). Similar tests have shown that under the same conditions for an explosion in the "nose-on" position, the necessary thickness of concrete (in.) will be about five times the cube root of the charge weight (lb.) of T.N.T. and that in the absence of a rear scabbing or "soffit" plate, the concrete cover on the inside reinforcing will be displaced more or less violently unless the thickness is about double that specified. The use of the steel soffit plate on the interior surface is desirable in almost all cases. Very often this plate can be made to take the place of shuttering during construction, and thus serve a double purpose.

Other experiments have thrown light on the effect of detonating a charge "nose-on" in a crater of the dimensions formed by the impact of a bomb of the corresponding size. Provided that the target slab is thick enough to resist the impact penetration and scabbing at (say) 900 ft./sec. the subsequent explosion is not likely to add greatly to the damage, particularly if a soffit plate is provided. The crater diameter is enlarged by the detonation, but its depth is often practically unchanged. It is a curious point that the thickness of concrete required to resist impact scabbing by M.C. bombs dropped from high levels, is very nearly the same as that required to resist the side-on contact explosion of the same bomb, which might occur in a low-level attack with an anti-ricochet device. The following table of proof thickness calculated from the equations of Chapter I and from the rules given above will make this clear:-

TABLE 9.2

PROOF THICKNESS FOR BOMB-PROOF ROOFS

Bomb (German medium-case type)	Penetration at 1000 ft./sec. (in) (i)	Thickness perforated at 1000 ft./sec. (in) (ii)	"Proof" thickness to resist scabbing (iii)	Proof thickness to resist perforation by sideways-on contact shot (in) * (iv)
50 kg. S.C.	15	26	35	34
250 " "	27	47	64	59
500 " "	36	61	82	71
1000 " "	41	75	111	93

We note that the difference between column (i) and column (iii) always exceeds 5/9 x column (iv), the thickness perforated by a nose-on shot.

The use of a high charge-weight ratio bomb would increase the thickness necessary to resist the sideways-on explosion without increasing the load on the aircraft, but in general this form of attack is not greatly to be feared. At best it can do only local damage in the interior, less serious than that which will be caused by an internal explosion after perforation of even a small bomb.

The experimental evidence on the question of the effect of decreasing the percentage of reinforcing is quite inadequate. The argument of Chapter VII suggests that a reduction from m per cent to n per cent in the percentage of steel, (retaining the same distribution) will reduce the energy-mass product in ratio not exceeding n/m. If, as is probably the case for the very large thickness-span ratios which we are dealing with here, a large proportion of the strength comes not from tension in the reinforcing but from arch action in the concrete, then reduction in the percentage reinforcing will have an even smaller influence on the resistance. An increase in thickness from t to t', however,

* The presence of rear reinforcing and scabbing plate is assumed.

produces an increase in the energy-mass products of at least $(\frac{t'}{t})^2$ or $(\frac{t'}{t})^3$ if arch action is important. Thus, as far as resistance to "bulging" and "general" deformation is concerned, a reduction from m per cent steel to n per cent steel is likely to be offset by an increase in thickness from t to t' given by:-

$$\frac{t'}{t} = \sqrt[p]{\frac{m}{n}}$$

when the parameter p is unlikely to be less than about 3.

The factor of real importance however, is not so much bulging as local damage, cratering and scabbing. Reinforcement has little if any effect in reducing cratering, but it has an important influence in retaining the scab. What is essential for this purpose is not that the reinforcing bars should be heavy, - the bars in the rear face of a slab are seldom cut, even when the slab is completely holed by an explosion,* - but that they should form a very close mesh, well anchored by through bars into the interior and thus capable of retaining the concrete even when considerable shattering has taken place. What is wanted therefore is not a high percentage of all-through reinforcement (a close mesh through the whole of the very thick walls and roofs which we are here considering will only increase the difficulty of pouring a high strength concrete) but a very close mesh of small bars near the inner surface, well tied to a comparatively wide mesh in the solid, which simply serves to prevent the general shattering to be expected in unreinforced concrete. The system of reinforcing shown in Fig. 9.6b, although it totals no more than 0.34 per cent by volume on the average would probably be capable of standing up quite as well as those whose tests are referred to in Table 9.1. Of course, it is assumed throughout that the reinforcing is such that the roof has an adequate factor of safety under ordinary static gravity forces. In most cases, this requirement will be met by the type of reinforcing which we have specified for providing resistance to explosion, particularly as the supported span of the roof is usually only a few times its thickness. Where a large open space is required beneath a heavy roof, it will sometimes be found that extra tension reinforcing must be added in order to provide an adequate factor of safety against ordinary bending forces.

It is not easy to specify exactly what constitutes this "adequate factor of safety". If the roof is so large that surface craters made by small or medium calibre bombs are not likely to cover an appreciable part of the total area, a normal working stress of perhaps 7 ton/sq.in. in the steel is, perhaps, permissible (note that since we are dealing here with <u>static</u> forces, it would be quite wrong to base calculations on the yield stress as in Chapter VII). If, however, for some reason, the roof is narrow and supported at its ends only, so that it forms a beam whose average depth might be decreased appreciably by a surface crater, a much lower working stress - say 4 ton/sq.in. - is desirable.

9.4 The attack by shaped charges

We have now to consider an entirely different form of explosive charge, which, although it explodes in air in close proximity to the target, is in no sense comparable with the ordinary shattering contact charge. It has been known for many years that a charge of cylindrical form having one end hollowed out into a conical cavity will produce results of unprecedented severity in the direction of the hollow end. Such charges, which are sometimes referred to as "Monroe" charges, have been developed for many purposes during the war. It has been found that their directional effect is much enhanced by lining the conical cavity with a metallic layer. When the charge explodes, this liner is ejected along the Axis of the cylinder at a very high speed, as a jet of liquid or gaseous metal. This jet is in effect a very high velocity projectile, and instead of shattering the concrete it bores a narrow hole, similar to that formed by an armour-piercing shot but much deeper. An 80 lb. shaped charge for example, is capable of forming a hole of 2 in. diameter clean through 10 ft. of reinforced concrete, and of producing a not inconsiderable blast effect locally on the far side.

* It is a curious feature that under these conditions the exposed bars may show several incipient "necks" like those produced just before fracture in a static tensile test.

These charges have not been used to any large extent in aerial bombing up to the present time but clearly they could be so used in at least two ways. Either a large number of charges could be dropped each of which would cause a small area of damage in the interior of the fortification, or a single larger charge might form a hole through which a smaller fragmentation or demolition bomb, originally placed behind the charge, might enter.

The very great penetrative powers of the shaped charge makes the "natural" method of defence - by increasing roof thicknesses - practically an impossibility; instead methods of defence based on the properties of the weapon itself must be contemplated. To produce its optimum effect, the charge must be offset, i.e. it must be fired a short distance (about one charge diameter) away from the surface attacked. If this surface is a perfectly plane one there is of course no difficulty in arranging this:- a false nose containing a rapid fuze can be provided in front of the explosive. If the roof is provided with a comparatively light "burster" placed some distance above the true roof, the explosion will take place in a position remote from that required for optimum performance. If the burster is inclined - for example, if it takes the form of an ordinary pitched roof - the situation may be still better, as not only is the fuze problem more difficult, but also the charge may be deflected from the normal before explosion, and thus forced to bore through a greater thickness of concrete before reaching the interior. Furthermore in these circumstances it is not unlikely that the "follow through" portion of the weapon, if it has one, will fail to find its way through the hole provided for it by the leading portion.

It is the common practice of the enemy to erect substantial pitched roofs over fortifications and large concrete shelters for camouflage or perhaps for aesthetic purposes. These roofs have not proved very effective, at least as far as camouflage is concerned, but it may well be that the further development of the shaped charge would make such measures a necessity.

9.3 Contact explosions in earth

Obviously, the confinement afforded by the earth, when a bomb explodes in contact with a concrete structure but below ground level, will greatly increase the forces to which the structure is subjected. Accordingly underground walls must be made heavier, if the same standard of resistance is required. Moreover, the shape effect is less important in earth, and the difference between "side-on" and "end-on" shots is much less marked.

In Table 9.3 we summarize the results of three full-scale experiments carried out to determine the critical thickness of concrete required to resist a side-on contact explosion in earth. These experiments were designed primarily to verify the dimensional theory under these conditions, and, although the method of support of the panels tested was not exactly scaled, it was found that over the small range of linear scales investigated there was no appreciable deviation from the theory. Comparison with small-scale tests, however, indicates that, as usual, the model work underestimates the damage slightly.

TABLE 9.3

CONTACT EXPLOSIONS ON CONCRETE - FULL-SCALE TESTS IN EARTH

Bomb	Charge-weight of Bomb (lb.)	Thickness of slab t(in.)	Reinforcement	Scabbing plate*	$t/W^{\frac{1}{3}}$	Damage
50 kg.S.C.6 (side-on)	52	49	0.75 Two thirds near inner face One third near centre	No.	13	Wall partly shattered and bulged outwards by 0.5 span. Concrete cover on interior face scabbed off.
250 lb.AS6 (side-on)	132	66	ditto	No.	13	Wall partly shattered and bowed 0.3 span. Concrete interior cover scabbed off, and projected across interior.
250 kg.S.C.6 (side-on)	275	84	ditto	No.	13	Wall partly shattered and bowed 0.43 span**. Concrete interior cover scabbed off & projected across interior.

* In subsequent small-scale experiments, it was shown that scabbing plate placed within the interior layer of reinforcing (which was left bare,) prevented the discharge of concrete from the interior surface, but did not reduce the bulging of the panel as a whole.

** See overleaf.

The experiments listed in Table 9.3 indicate that a concrete wall, reinforced 0.75 per cent by volume of steel, with two-thirds of the reinforcing at the inner face, and subjected to the sideways-on contact explosion in earth of a bomb of charge-weight W lb. (TNT or amatol) will bulge a maximum distance equal to about half of the span if its thickness is given by $t/W^{\frac{1}{3}} = 13$. To reduce this deflection to our standard value 1/7th span, would require $t = 17W^{\frac{1}{3}}$. Experiments in the United States[7] have given a very similar result.

In the absence of a scabbing plate the concrete cover over the inside layer of reinforcement is detached and projected with some violence into the interior. The use of a steel lining is therefore as desirable here as when the explosion takes place in air.

9.6 The minimum thickness of floors

In the above paragraph we have been concerned mainly with the specification of the minimum thickness of an underground wall. The situation with regard to floors is somewhat different particularly if the fortification is small. (In a large building, capable of resisting penetration, an explosion under the floor cannot occur, except near the exterior walls from a bomb entering the ground obliquely, and so appropriate reductions of floor thickness in the interior can be made). An investigation of the position in which the explosion can take place in order to inflict a specified degree of damage on a floor of thickness $5W^{\frac{1}{3}}$ with the standard reinforcing has been made and its results are shown in Fig. 9.1. It should be noted that the ratio deflection/span used to define "heavy damage" is less than we have considered acceptable for walls. For a small "pill-box" of type investigated (about $48W^{\frac{1}{3}}$ in diameter; say 24 ft. across when the attack is by 500 lb. bomb) the decisive factor is not the damage to the floor itself but the fact that the whole structure is thrown into the air with velocity large enough to cause injuries in the interior whenever the explosion is within the volume indicated as causing "light damage". If the structure forms part of a larger unit, its velocity will of course be reduced but at the same time the local damage will become more severe, as the block movement of the whole is prevented. In Chapter XI we discuss in some detail the parallel problem of the effect of the movement of supports on the damage to a panel wall. All that need be said here is that whether the unit stands by itself, or forms part of a large structure, the reduction of the floor thickness to $5W^{\frac{1}{3}}$ can only be considered acceptable if the bomb is prevented from exploding in the area marked "light damage" in Fig. 9.1.

9.7 Geometrical considerations in design

In the preceding paragraphs we have laid down the fundamental dimensions of the fortification; we have showed that those portions of the exterior surface which are below ground level but are not inaccessible to contact explosions must be made far stronger than the above-ground portions, and we have stated that if the aim is to secure complete protection against a given size of missile, then the roof, and the above-ground portions of the walls must be approximately of the same thickness.

Our problem now is to examine the geometrical forms which can most achieve these standards most economically. Two generalizations can be made a priori

(i) A fortification of approximately cubical form will involve less expenditure of concrete per unit volume protected than (say) a flat structure of larger area.

(ii) Surface fortifications will be in general more economical than those partly or entirely sunk in the ground.

Several possible forms each intended for protection against the 500 lb. bomb are shown in Fig. 9.2[9]. In these forms, the above-ground wall thickness is somewhat below our recommendation, and the roof thickness somewhat above, because of the severity of damage resulting from a perforation when compared with even the closest near-miss. The floor thickness has been reduced to 36 in. (about $5W^{\frac{1}{3}}$) provided that the bomb cannot reach the "medium damage" zone as shown in Fig. 9.1 unless its path length in the soil exceeds 20 ft. In practice, it can be shown

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** (see previous page)
In this test the edge support was inadequate and gave way somewhat; the total deflection at the centre of the wall was therefore greater than the bulge.

that even if the path length of the bomb in this material is 30 ft. the probability that its track will bring it into the danger zone is extremely small. In case 2, where a burster slab is used to prevent the bomb reaching the zone in which floor damage is to be expected, the thickness of this slab is taken as only $1\frac{1}{3}$ times the penetration of the bomb. Since the slab is earth-backed and not suspended, the effect of scabbing in increasing perforation will be less marked. For the same reason, little or no reinforcing is necessary in a burster. A further possibility is to place the burster vertically below the exterior wall, as a "skirt" or "curtain" wall.[10] So placed, it is equally effective in preventing the bomb from reaching the floor-damage zone, and although it may be damaged by earth-shock from near-misses this damage is without importance since it does not affect the fortification itself.

9.8 Structural considerations in design

It will be quite clear that constructions of the type shown in the figure gain much of their strength from their continuity. Weaknesses at the junction of roof and walls, or of walls and floor, must be eliminated. It is essential that the concrete throughout the fortification should be as nearly as possible continuous and homogenous. In practice however construction joints between batches and pours are inevitable. A few principles can be laid down as to the way in which such joints should be sited.

(i) Joints should if possible run parallel to and not across the exterior surfaces, i.e., they should run horizontally in roofs, and floors; in walls vertically and parallel with the direction of the wall. All units should, however, be poured with the fewest possible number of joints. Not more than two or three lifts should be necessary in even the thickest roofs.

(ii) In roofs of very large area vertical joints may be essential both from considerations of thermal expansion and because the quantity of concrete required to pour a single lift over the whole area is beyond the capacity of the available plant. In these cases the vertical joints should be differently placed in the various lifts, so that no vertical joint runs through more than say one-third of the total thickness, and, if possible, all joints should be situated over division walls.

(iii) It may well be desirable to provide additional shear reinforcing at joints in the concrete, so that the shear strength at these points is as great as elsewhere.

It is also essential that reinforcement should be made as continuous as possible. This can best be done by welding successive lengths of bars together, or by hooking with an adequate overlap. Where the end of a bar is held by bond with concrete only, a lap length of not less than 72 diameters is recommended.

In prescribing continuity we must, however, make a clear distinction between those parts of the structure which are essential and those which are not. In Fig. 9.2 cases 1, 3 and 4, the structure forms a single unit, and everything must be done to ensure its continuity. In case 2 the structure itself is surrounded by a burster slab whose sole purpose is to prevent the bomb reaching a place in which it might damage the essential unit. It would be wrong under these conditions to make the burster continuous with the structure; it is quite true that to do so would decrease the damage <u>to the burster slab</u>, but only at the expense of increasing damage <u>to the fortification itself</u>. Damage to the burster is quite without importance and so the risk, however, small, that a continuous joint between burster and floor will increase the damage to the latter, should not be run.

A similar principle has been suggested for the design of fortifications in which one part has much greater importance than the remainder. As an

example of such a case we may quote the large gun emplacement, shown diagrammatically in Fig. 9.3. Here the vital item is the gun itself, but various magazines, stores, etc., are also necessary. The gun, on its large foundation slab is placed in the centre, and round it are constructed the "supply" shelters. A direct hit on the gun, capable of penetrating its overhead protection puts it out of action, but a direct hit on a magazine does not necessarily do so, since there are other magazines which may be drawn on. The surrounding structures must prevent penetration below or nearly below the foundation slab of the gun, as even a small movement of this slab will have fatal effects on the accuracy of fire. Finally, the displacement of the subsidiaries, resulting from a near miss must be prevented from causing any movement of the central slab. Clearly this is best done by permitting a completely free joint, or even a small air-gap between the central slab and the surrounding ring. Each unit - the gun, and the "supply" ring - must be as rigid, and as closely integrated as possible, but movement of the one relative to the other should not be retarded in any way.

9.9 Special technique during construction

We have already referred to the necessity for careful control of the pouring procedure during construction, the necessity for careful siting of joints, etc. Some other points arising from the very great thickness and weight of units are worthy of consideration.

(a) Placing of reinforcement. In fabricating a very thick slab, a mesh of reinforcement which may be 16 or 20 ft. thick must be laid beforehand, and must form a rigid framework, which will not distort awkwardly during pouring. The heavy reinforcement running through the thickness of the slab, which we have recommended as a precaution against scabbing, will be useful in imparting the necessary rigidity to this framework during erection. A system of reinforcing which has been very widely used, however, is the so-called "cubic mesh", which consists simply in three mutually perpendicular sets of bars of the same diameter, with the same spacing (usually 1 ft.) in each direction. This system is clearly not the most economical in steel, since it affords neither a concentration of bars on the inner face, nor a reduction near the outer face. On the other hand, it is of course, extremely simple in erection and this consideration has frequently outweighed that of economy when fortifications have had to be erected by unskilled or semi-skilled labour.

(b) Pouring of concrete. Given that reinforcement is placed at about one foot average spacing it is usually considered that aggregate size must be limited to a maximum of 2 inches*. Larger aggregates will give better resistance to penetration (for a given water-cement ratio) but difficulties of consolidation will generally preclude their use. Even with this limitation the problem of achieving a high density concrete when pouring through a 16 ft. thick mesh of steel bars is considerable, and necessitates the use of a much wetter mix than would be desirable on other grounds. Of course, when the concrete surface is accessible, ordinary methods of consolidation by vibration can be used, and thus near the upper face of a roof the large aggregate size and low water-cement ratio so desirable in resisting penetration can be introduced particularly if, as we recommend, the percentage reinforcement has been substantially reduced in this region. In principle, on the inside face of a slab, the reinforcing is the dominant factor, and the design of concrete must be adapted to suit the steel. On the outside face the converse is the case. We have here an additional argument for pouring a roof in horizontal layers rather than in vertical sections.

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* Of course, the presence of a very close reinforcing mesh on the inner face of a slab like that shown in Fig. 9.6 can be disregarded in selecting the maximum aggregate size. It is our deliberate intention that the aggregate should not pass through this mesh.

(c) The provision of the soffit or spalling plate. We have repeatedly argued in this chapter that all interior surfaces, with the possible exception of floors, should be given a steel lining. The practical engineering of this requirement can be approached in several ways. Two of the three here described are particularly adapted to roofs while the third is applicable mostly to walls.

(i) The "filler joist" method in roofs. This method consists simply in placing steel joists across the shorter span of the roof usually at about 1 - 3 ft. spacing, and filling the gaps between them with steel plate preferably welded to the lower flange, as shown in Fig. 9.4a. It is essential that the joists should be long enough to ensure that they will not pull off the supporting walls even when very badly bowed downwards. Their end anchorage can be improved by passing the vertical reinforcing bars in the supporting walls through holes drilled in the flanges, so as to ensure that the joist extends when bowed downward, and does not merely pull out of the concrete. If this is done it is permissible to include the steel in the joist in the computation of the percentage reinforcing in the lower layer of the roof, and thus to reduce somewhat the weight of steel in the body of the concrete, though this should not be allowed to fall below about 0.1 per cent, the minimum necessary to prevent widespread shattering. The steel in the scabbing plate itself, however, should not be included in this computation, since the roof can be deflected without appreciably extending it. The plate should not be less than 3/16 in. thick. Where possible joists should be made continuous over partition walls, and between successive portions of the building, though not, of course, where the free joints referred to above are required.

(ii) The "steel troughing" method in roofs. This method, illustrated diagrammatically in Fig. 9.4b, consists simply in covering the area of the roof with steel troughs placed across the shorter span and welded together. It is again essential that the troughs should be prevented from pulling off their end support, and accordingly wall reinforcement should be passed through holes drilled for the purpose. It is sometimes recommended that the bottom layer of steel in the roof concrete should also be either passed through the troughs or welded to them, in order to ensure bond between steel and concrete over the whole length. Since the steel only plays its real part when the concrete is already shattered as a result of spalling this measure may not be necessary.

Here again an allowance can be made for the weight of steel in the troughing in computing the percentage of reinforcement in the roof.

Both these methods have the advantage that they provide shuttering on the underside of the roof capable of sustaining a considerable load of concrete during pouring, and thus greatly simplifying the support of the roof during construction.

(iii) The plate-between-bars method in walls. It is clear that if methods (i) and (ii) are adopted both in roof and in walls difficulties may arise in securing an adequate anchorage at the joint for both sets of members: furthermore the strong shuttering afforded by these methods is not required on a vertical surface. For these reasons, the alternative shown in Fig. 9.4c has been evolved, and has proved satisfactory in an experiment. Here the steel spalling plate, which again must not be thinner than 3/16 in., is inserted between the horizontal and vertical bars of the inside reinforcing layer. The bars on the interior side of the plate, which of course are not in concrete at all should run across the shorter span of the wall. The usual precautions must be taken in

anchoring these bars. They may be hooked over horizontal bars in floor and roof, or bent to run horizontally for a length not less than 72 diameters, but it is essential that if the latter course is taken they should pass below the longitudinal reinforcing in the floor (or above that in the roof) so as to prevent them pulling out of the surface. In a multi-storey building, the vertical reinforcing should be made continuous in the whole height either by welding or hooking successive lengths together. The scabbing plate cannot usually be adequately tied at its edges, and so no allowance should be made for it in computing the percentage steel in the wall.

(iv) Other methods of retaining the scabbing plate. Various other devices have been suggested for retaining the soffit plate in position on the interior surface on the concrete. One such consists in passing ties round the reinforcing in the body of the concrete, and welding them to the surface of the plate. It has been suggested that these ties should be provided at a rate of 0.3 sq.in. per sq.ft. area. In the view of the writer such methods do not really afford an adequate solution of the problem. In at least one case they have been proved experimentally to be ineffective.

(d) The support of concrete during pouring. It will readily be appreciated that to pour a lift of perhaps 6 ft. in thickness over an area of roof having a minimum span perhaps 60 ft. at a height of 60 ft. above the ground, presents a considerable problem of structural engineering on its own account*. The ordinary methods of support with timber or steel shuttering are quite inadequate in such a case. Undoubtedly the best solution is to extend the principle noted above of carrying the concrete on the plate and joists which will ultimately form the bottom surface of the roof. To carry the tremendous load involved in this case on ordinary joists would, however, involve the use of unnecessarily large members, and accordingly each joist is replaced by a steel truss, of total depth usually about two-thirds of the roof thickness. In the case of a roof of total thickness 12 ft. to be poured in two equal lifts, the trusses might be placed at three foot centres, and have depth 8 ft. The central bending moment per truss for span 60 ft. after the first pour is 1.18×10^6 lb.-ft., so that the tension in lower member at the centre is 1.475×10^5 lb. It is unnecessary to provide for any "factor of safety" in the trusses, or even to keep within the elastic limit, since this load occurs once only, and for a short time while the concrete is hardening. A working stress of 10 tons/sq. in. is therefore quite acceptable, and accordingly joists of 10" x 4½" x 25" are adequate. The top member of the joist must be laterally braced to prevent buckling, and the ordinary slab reinforcement can often be used for this purpose. The spalling plate, for which a light troughing can often be used to provide stiffness, is welded on to the lower flange of the bottom members in the usual way. In computing the percentage reinforcement required in the concrete, the steel in the lower members of the trusses can be taken into account, but not the remainder since it is very badly placed for most purposes. The first lift of concrete must of course be allowed to harden before the second is poured, and the whole reinforcing system must be more than sufficient to sustain the final static load due to the weight of the slab.

In some cases in fortifications having the lower surface of the roof at or near ground level, a heroic expedient has been adopted. The walls are first constructed in trenches of appropriate dimensions dug for the purpose. The lower-face steel and roof reinforcing are then placed in position and the whole roof is cast on the ground. After an appropriate interval to allow for hardening of concrete, the earth is then

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* This was approximately the problem which faced the enemy during the construction of the Atlantic coast submarine pens.

excavated from under the roof slab, and finally when excavation has proceeded to the specified depth, the floor is placed in position. The floor in this type of structure is usually a light one, and floor damage is prevented by a burster slab forming an extension of the main roof. Where a semi-sunk or fully sunk construction is required, this method has much to recommend it, and, indeed, its simplicity is an argument in favour of the selection of semi-sunk forms of construction where a very high degree of protection with corresponding enormously heavy roofs is required. Of course, the condition of the site is always a dominating factor in such designs. The soil may be too hard to permit large-scale excavation, or alternatively too waterlogged to allow sunken construction.

(e) The repair of bomb-proof structures. Any structure, even the most massive is liable to bomb damage of more or less severity. If the design is completely successful, and the weapons used are no more powerful than those contemplated by the designer the damage will be restricted, in the case of direct hits, to surface craters with perhaps some slight bulging in the steel-work on the underside of the roof at the point struck, and in the case of a near miss, to cracking in the concrete in the walls with some bulging of the inner surface. In such cases an effective repair can be carried out simply by patching the exterior face with plain concrete.* If there is no bulging on the inside face such a repair will practically restore the original strength. If some bulging has taken place, the status quo cannot quite be restored, but a compensating strength can be achieved by increasing the thickness over the damage span with an additional layer of concrete. If the original static strength (in the case of a roof) was insufficient to sustain the additional weight, then additional support must be provided in the interior in the manner described below.

If severe damage has been done, if the roof or walls are holed or very badly bulged, it must be assumed (indeed it will probably be obvious) that some of the inner-face steelwork has been effectively destroyed. To restore it exactly will necessitate cutting out the original members - a lengthy operation if they are, as they should be, well embedded in concrete at their ends. A much easier method is simply to cut away the loose ends of the original inner-face steelwork, and erect a new frame consisting of steel members supported at their ends either on concrete posts, or on continuous steel stanchions. Having thus provided the necessary support on the inside face, the hole or bulge can be patched with concrete on the outside as before. If an open hole is being repaired, it can be seen whether the reinforcing bars in the interior of the concrete have or have not been cut. If they have, the loose ends can be straightened and welded together to provide the necessary reinforcement for the new concrete. If they are still intact, the fact that they are somewhat distorted is probably of no consequence. When the bomb has not blown an open hole, but has caused a severe bulge, it can usually be assumed that the reinforcing bars in the solid have not been cut, unless the concrete is so badly shattered that it can easily be removed, leaving an open hole.

We have now touched on most of the main points which arise in the design of heavy shelters and fortifications. We devote the few pages remaining in the chapter to more detailed consideration of three individual designs, differing widely in size and strength.

9.10 Commentary on three existing designs

(a) The original "bomb-resisting" shelter [11] One of the original "bomb-resisting" shelters designed in 1939 is shown in Figs. 9.5a and 9.5b. At this time practically none of the experimental work described in this book had been carried out, and the designers had only the most fragmentary information on which to proceed. How would more modern information modify their plan ?

First, with regard to the dimensions of the structure as a whole, it will be noticed that the roof thickness exceeds that of the walls above ground level. That is to say, the roof would only be perforated by a bomb larger than that which, exploding sideways-on in contact would blow a hole in the walls. This, of course, is a perfectly logical and correct design. Not only is the chance of a direct hit much larger than the chance of a near-miss so exactly placed as to give the effect of sideways-on contact, but the consequences of perforation are far more serious than those of any external explosion, even one capable of blowing a hole in the wall. In the former

* Loose pieces of concrete must be removed from the crater before the new patch is poured.

case all the occupants of the shelter will be exposed to severe risk, in the latter case only those near the hole, who are likely to be struck by flying pieces of concrete, are in much danger. Three out of the four compartments will probably be safe. Thus it is the perforation that must be countered as a first priority. The wall thickness below ground level is made consistent with that above ground level; again a quite sound procedure, although the probability of an effective contact shot is perhaps a little higher than above the surface since the attitude of the bomb is less important. When they came to the floor, however, the designers did not continue with the policy of providing less protection against unlikely events than against probable ones. They realized that for equal resistance to explosion, floor and sub-surface walls must be equally thick and they designed accordingly. But a contact shot below the floor is definitely more improbable than one against the walls, and so a logical policy would reduce the thickness there. Probably a modern design would show a floor thickness reduced to about 3 ft. 6 in. The increased wall thickness required below the surface would probably be placed outside rather than inside the above-ground walls in order to secure increased internal volume with only a small additional consumption of material.

When we come to the reinforcing diagram, Fig. 9.5b, we see that ideas have changed rather fundamentally. Except for some additions on the underside of the roof, the steel is roughly uniformly distributed between inner and outer faces, whereas the contemporary plan is to place the greater part of the steel on the inside, most of the remainder near the centre, and almost none at the outside. The idea of scabbing plates for walls, as well as roof is comparatively recent, and we have already stated that we consider the means adopted here for anchoring the roof scabbing plate (by vertical links) to be inadequate.

(b) A German "Bunker" shelter[12] In Fig. 9.6a is shown a plan and section of one of the large "Bunker" shelters built by the Germans in the years 1941-43. The one shown is one of the most recent, and was in fact left unfinished in 1944. The idea that roof and above-ground walls should be of the same thickness, has been adopted, though, as we saw above, it is very questionable whether this arrangement is in fact the best. The intention has apparently been to provide complete protection against the 1000 lb. bomb, and to neglect the risk that a larger penetrating bomb might be used, and it is arguable that the policy was justified by events - very few delay-fuzed bombs larger than 1000 lb. were in fact dropped on Germany.

A much more serious error has however been made in the internal design of the shelter. Only the roof, walls and outside wall footings have been reinforced. Internal walls have been constructed of mass concrete or brick. Even a quite small internal explosion, or a large external explosion near the door might be sufficient not only to demolish such walls, but to convert them into most dangerous missiles which could not fail to cause many casualties. The percentage reinforcing necessary to prevent this disintegration is as we have seen very small, not more than 0.06 per cent, but its presence is essential in almost all construction for protective purposes.

In Fig. 9.6b we show the wall reinforcing arrangement which we have already instanced as being one of the best that has been devised. True, the writer would prefer to omit the concrete cover on the inside face, and to replace the close mesh of small bars shown in the diagram by continuous strips of sheet steel passed through the large U-frames, with narrower pieces welded on to close the gaps between frames. It may seem that this change is difficult to carry out, and that it does not provide any large increment in safety. The reply may be made that since the arrangement avoids the use of internal shuttering it will not on balance lead to an increase of labour requirement. Further, we may remark that a piece of the internal cover concrete, say 1 ft. square and 2 in. thick weighing 2 lb. does not have to travel very fast to cause a serious injury.

(e) A typical "very heavy" fortification[13] Fig. 9.7 shows the immense concrete fortification constructed by the Germans at Siracourt in the Pas de Calais. This erection was of course cast on the ground, and the subsequent excavations were never completed. Its general shape was presumably laid down from considerations of the purpose for which it was required; apparently a chamber about 14 ft. high 50 ft. wide and 600 ft. long with a single large entry had to be made as nearly as possible bomb-proof*.

For this purpose, the general shape of the section can hardly be improved on. The burster and the short wedge-shaped walls make it very unlikely that a bomb will ever penetrate below the floor. The roof is, nominally at least, proof against the largest bomb at that time in our armoury - the 12,000 lb. M.C. known as "Tallboy". The transverse roof reinforcing was much as we have recommended, and there was a soffit plate supported on rolled steel joists in the manner of Fig. 9.4a. Yet this structure was attacked and so seriously damaged that the whole project was abandoned.

The roof plan in the diagram shows how this happened. The designer had made two errors, one slight, the other serious, and, with remarkable consistency, the two bombs shown on the plan exploited these errors to cause damage, one slight and the other serious. Let us consider first the near-miss shown on the top edge of the plan. This near-miss destroyed a length of burster, but this was of course, of no consequence, since the burster is there for that purpose. The designer had realized that it was necessary to use a "unit construction" to make a joint between the burster and the main structure which would enable the former to move freely without damaging the latter. Instead of carrying out this plan logically however, he allowed the roof to lap a few feet over the burster, as shown in the section, and thus he prevented free relative movement. The near-miss bomb, therefore not only broke up the burster slab but also caused a complicated system of cracks to spread through the main roof from the point where the burster lifted it. The error here was slight - a mere matter of stepping the joint between roof and burster instead of leaving it plain, and the damage also was not very serious.

In designing the roof slab, however, undue attention was given to the problem of contraction. Every few yards along the length of the building there was a completely discontinuous butt joint through which no reinforcing bars were passed, and in which a layer of precast blocks were placed, presumably with a view to allowing free relative movement of adjacent sections. The direct hit indicated on the plan fell exactly on one such joint, penetrated some distance and in its explosion caused very serious damage, which if the excavation had been complete at the point, would probably have amounted to collapse, over the two portions of the roof between which it struck. Had longitudinal continuity been maintained, the damage would have been much less severe both because the absence of the joint would have reduced the penetration of the bomb and because the damaged portions would have received much greater support from their neighbours. True, some slight damage might have been transmitted to these adjacent portions had the roof been continuous. But for the proper working of the building it was essential that the whole length should be intact. To adopt a construction which made it easy to put the whole out of action by destroying a single section was therefore, as the event proved, totally incorrect.

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* There is reason to believe that the designer had especially in mind attack by the British 2000 lb. armour-piercing bomb. He was not informed as to the development of a larger missile - Tallboy.

TABLE 9.1

CONTACT EXPLOSIONS ON CONCRETE - FULL-SCALE TESTS IN AIR

Bomb	Charge-weight of bomb W lb.	Thickness of slab t (in.)	Reinforcement	Scabbing plate	$t/W^{\frac{1}{3}}$	Damage
50 kg. S.C.4 (side-on)	55 TNT	24	0.7% two-thirds within 1 ft. of inner face	No	6.3	Slab completely perforated, forming hole 3 ft. in diameter.
500 kg. S.C.5 (side-on)	500 lb. (Approx.) TNT	72	1% two-thirds within 1 ft. of inner face	Yes	9.1	Surface crater 11 ft. diam. x 2 ft. in deep concrete through the whole thickness, shattered, but retained on reinforcing in rear surface. Bulge at rear 31 in. on a clear span of 18 ft. Soffit plate displaced.
50 kg. S.C.5 (side-on)	55 lb. TNT	39	0.38% two-thirds near inner face	No	10.2	Surface crater 4 ft. diam. x 9 in. deep. Concrete on the rear face behind inner reinforcing layer scabbed off over area 9 ft. x 6 ft. Permanent deflection of reinforcing 3 in. on 6 ft. span.
Bomb replica4 (cased charge) side-on	$1\frac{3}{4}$ oz. PE *	3	0.66% five-eighths near inner face	No	6.3	Slab completely perforated, forming hole 5" in diameter.
Bomb replica4 (cased charge) side-on	$1\frac{3}{4}$ oz. PE	$3\frac{3}{4}$	0.53% five-eighths near inner face	No	7.8	Surface crater 6 in. diameter x 1 in. deep. Very heavy scabbing at rear. The rear reinforcing failed to retain the shattered concrete in a volume 5" diameter x 2" deep, and a much larger area was shattered, but retained.
Bomb replica4 (cased charge) side-on	$1\frac{3}{4}$ oz. PE	$4\frac{1}{8}$	0.49% five-eighths near inner face	No	8.6	Surface crater 6 in. diameter x 1 in. deep. Very heavy scabbing at rear. Rear reinforcing failed to retain concrete in a volume 3" diameter x 1" deep, and a much larger area was shattered, but retained.

* For a note on the use of this explosive in small-scale tests, see Chapter VI.

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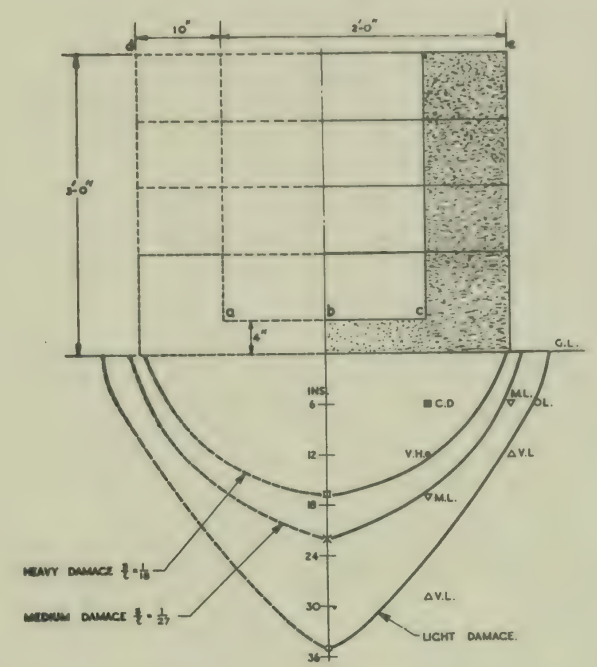
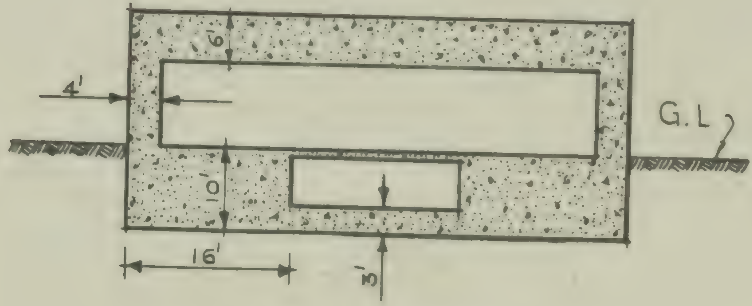
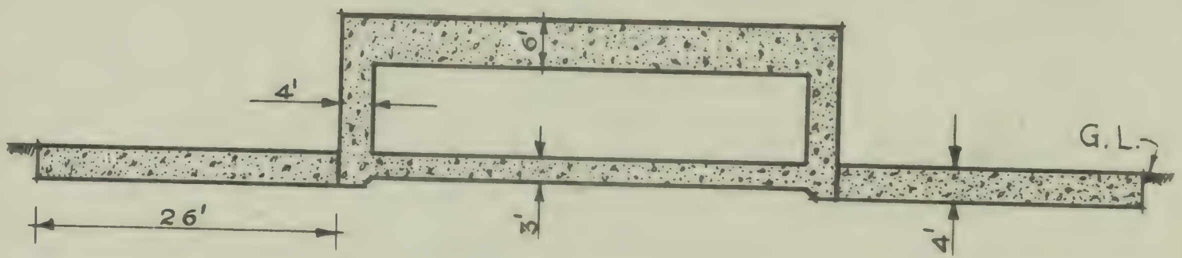


C.D. COMPLETE DESTRUCTION	■	M.L. MEDIUM-LIGHT	▽
V.H. VERY HEAVY	●	L. LIGHT	○
H. HEAVY	□	V.L. VERY LIGHT	△
M. MEDIUM	×		

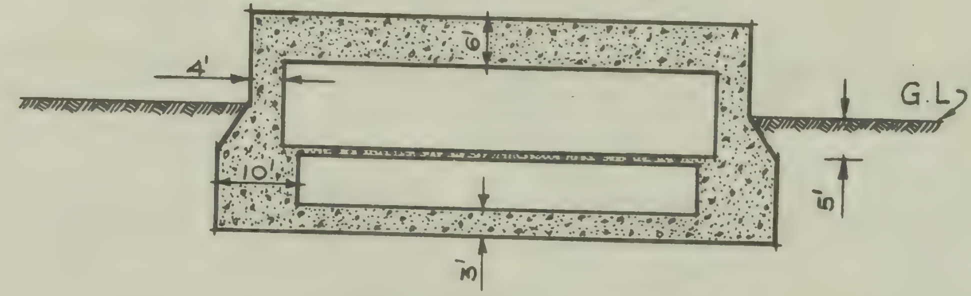
FIG 9·1 ZONES OF DAMAGE



Case 1 (Surface)



Case 2 (Surface)



Case 3 (Semi-sunk)

Note:- All dimensions are in feet.

Case 4. (Sunk).

Diagrams of Shelters

Fig: 9.2

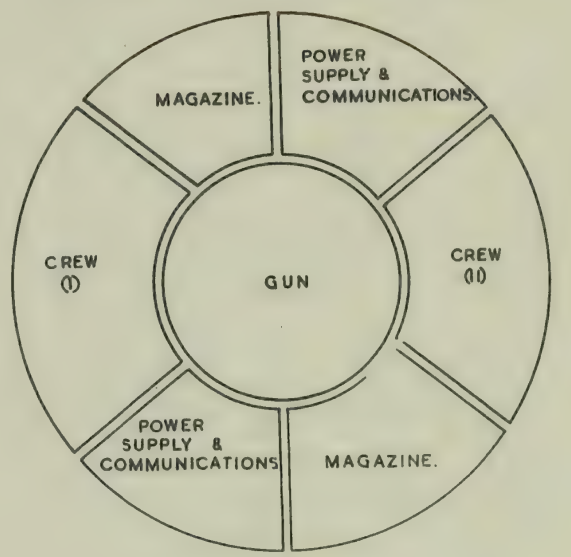


FIG. 9.3.

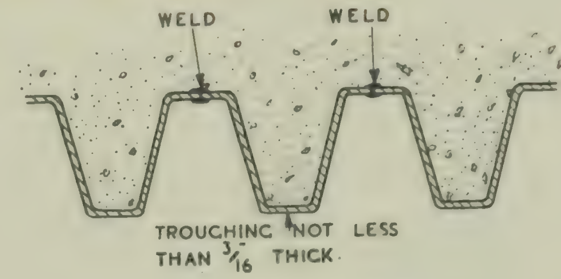


FIG.9. 4. b.

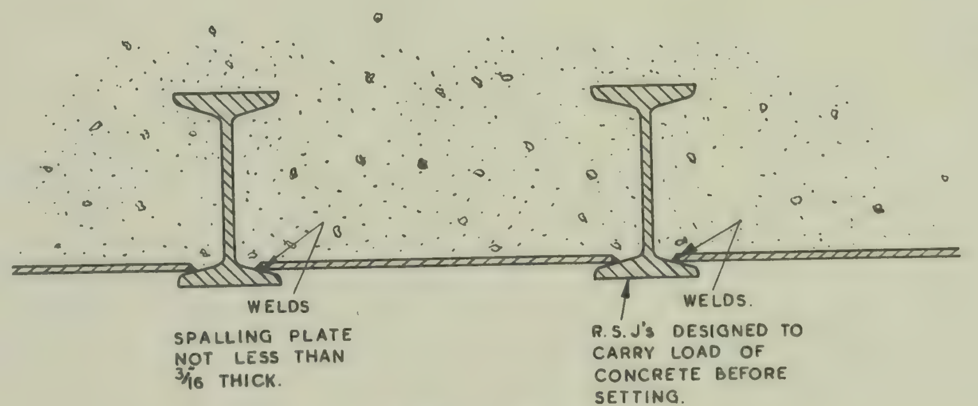


FIG. 9.4. a.

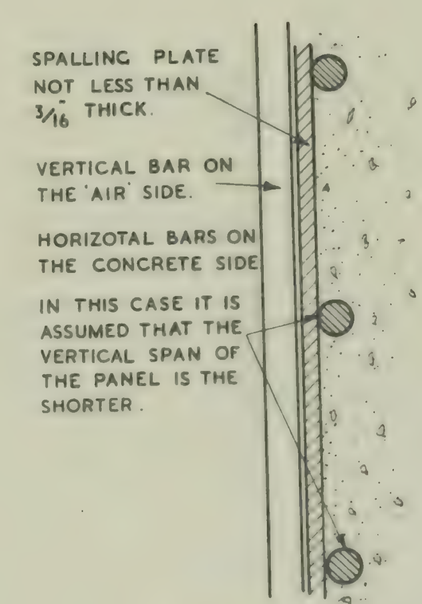


FIG.9. 4. c.

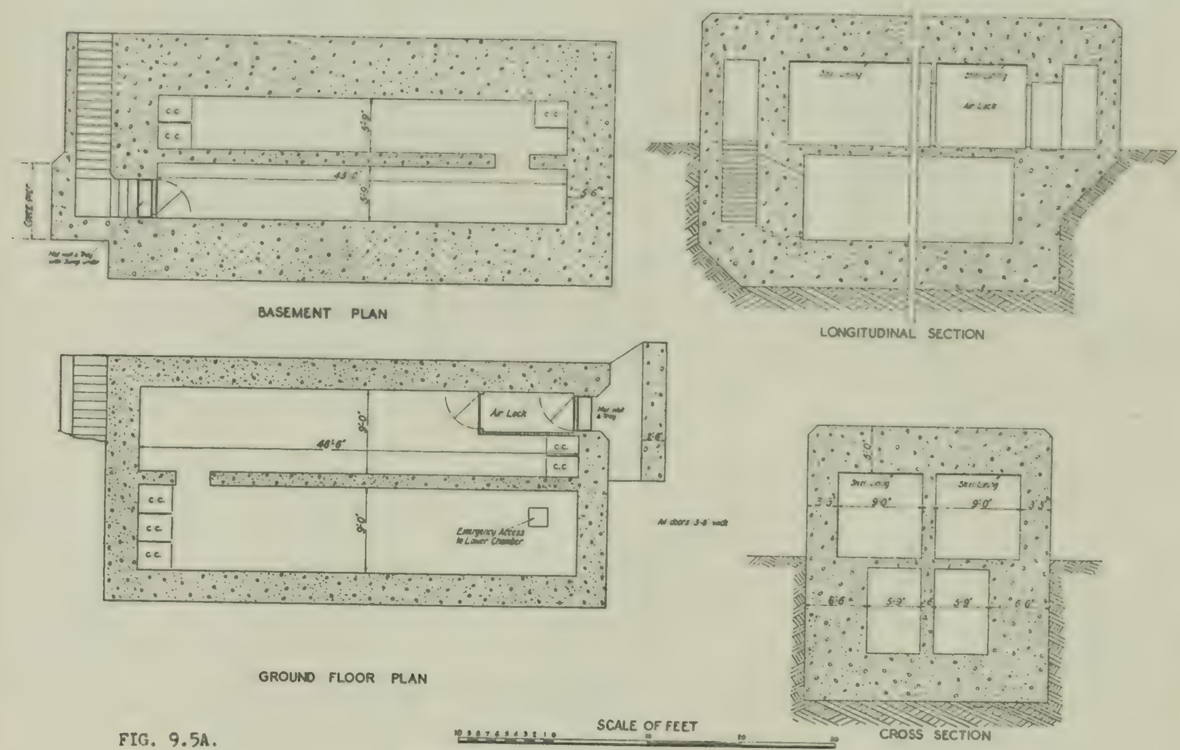


FIG. 9.5A.

RECTANGULAR SHELTER FOR 200 PERSONS

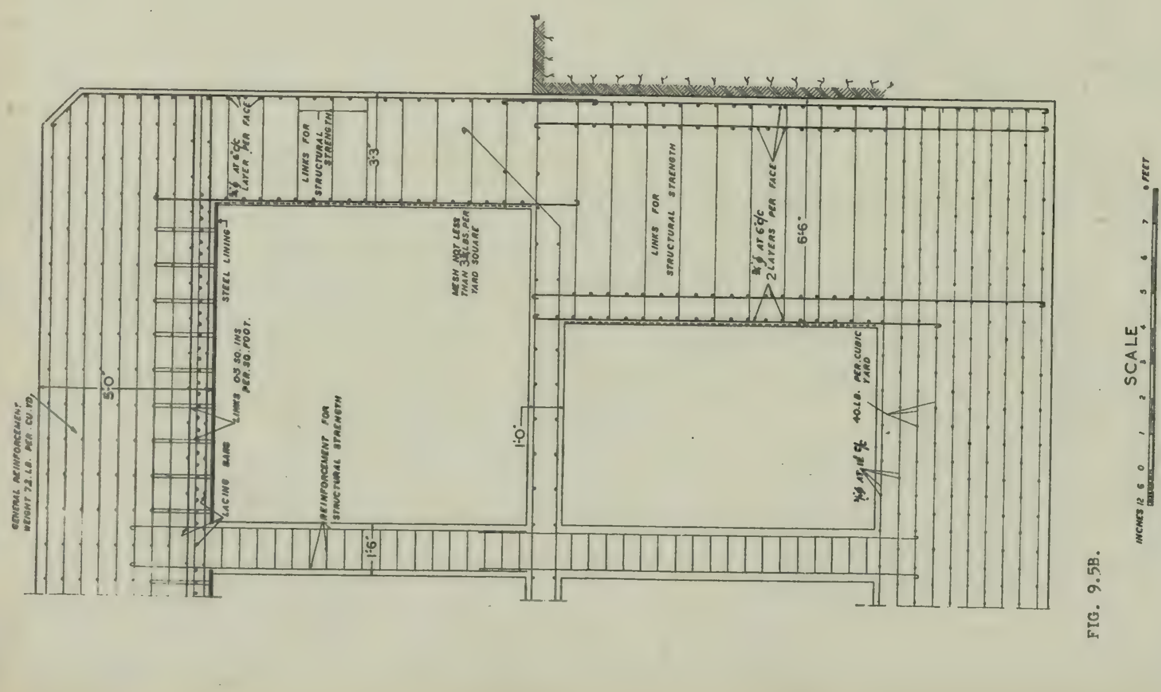
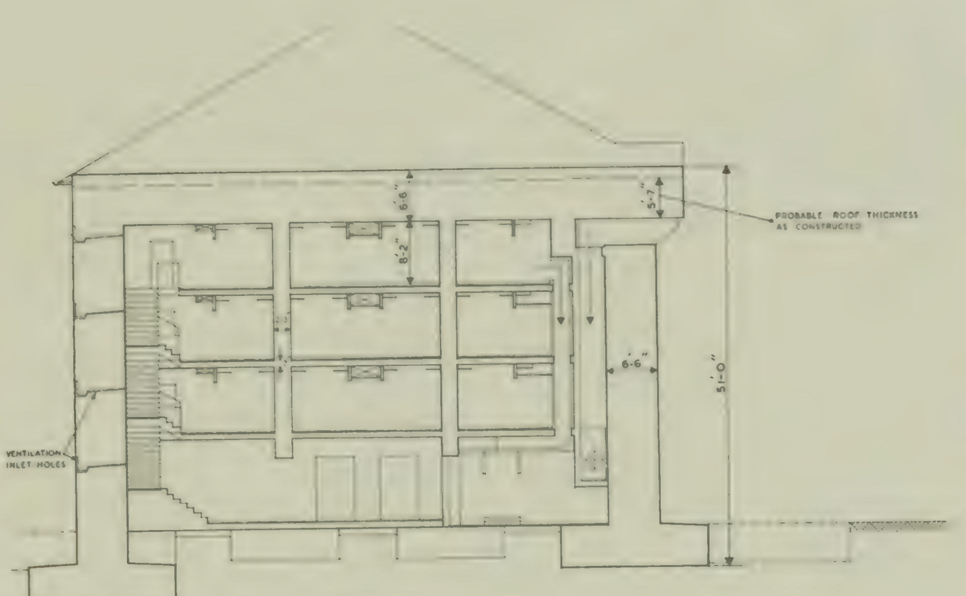
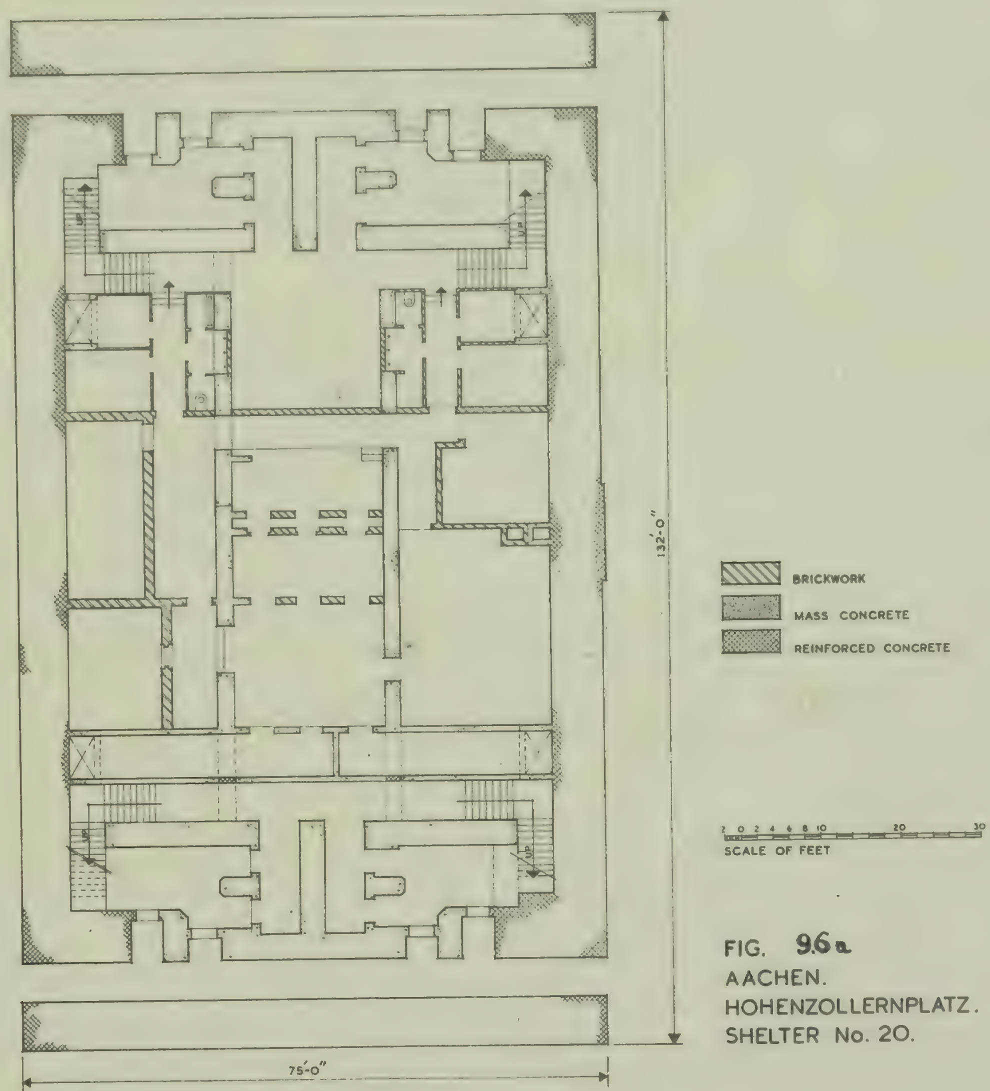


FIG. 9.5B.

DETAILS OF REINFORCEMENT

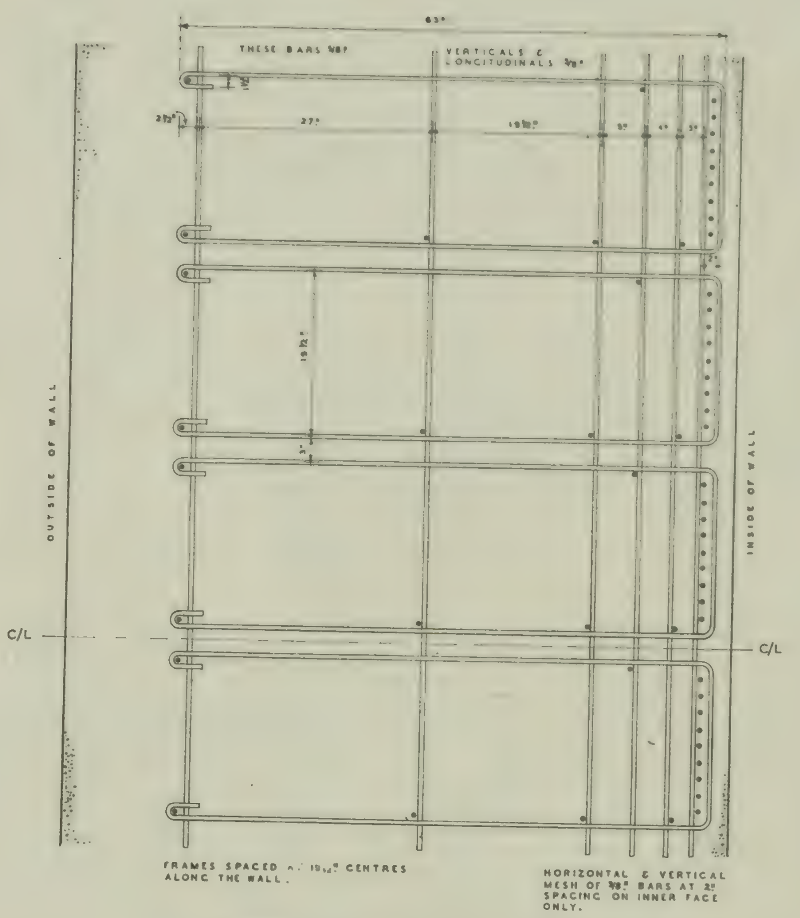


·SECTION·



·PLAN·

FIG. 9.6a
AACHEN.
HOHENZOLLERNPLATZ.
SHELTER No. 20.



CONCRETE COVER ON INSIDE ABOUT 2 INCHES, ON OUTSIDE ABOUT 12 INCHES.

NOTE - ALL JOINTS WIRED: NO WELDING.

FIG. 96b · WALL REINFORCING · HOHENZOLLERNPLATZ ·
(SHELTER NO. 20.)

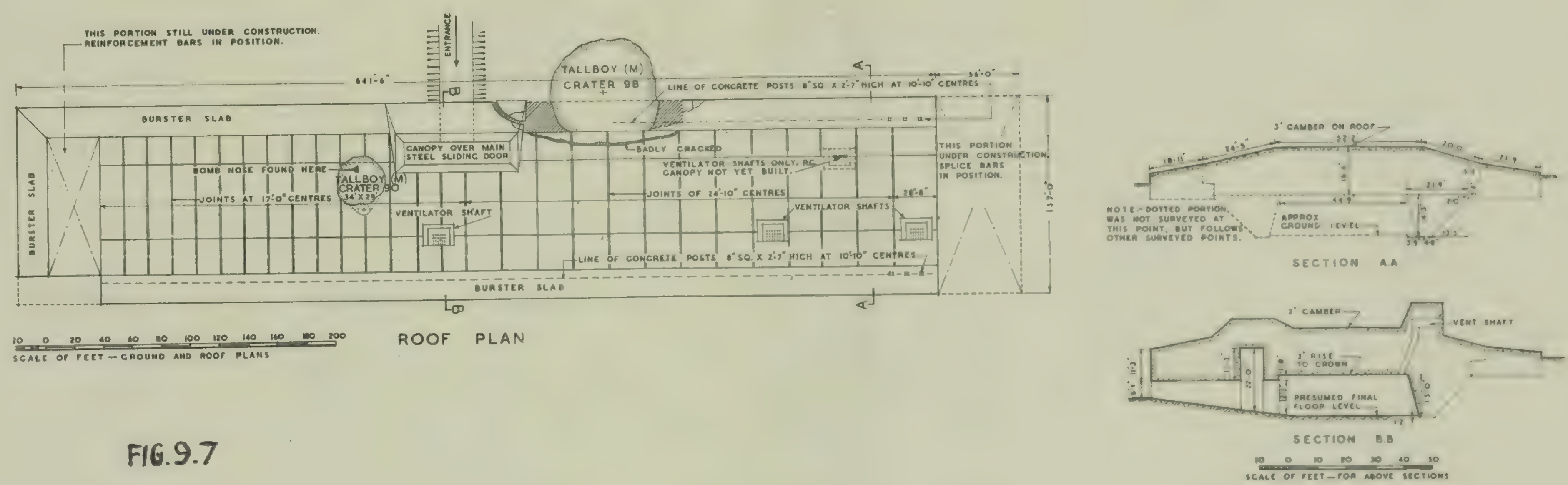

THIS PORTION STILL UNDER CONSTRUCTION. REINFORCEMENT BARS IN POSITION.
ENTRANCE
641'-6"
TALLBOY (M) CRATER 98
LINE OF CONCRETE POSTS 8" SQ. X 2'-7" HIGH AT 10'-10" CENTRES
56'-0"
BURSTER SLAB
CANOPY OVER MAIN STEEL SLIDING DOOR
BADLY CRACKED
VENTILATOR SHAFTS ONLY. R.C. CANOPY NOT YET BUILT.
THIS PORTION UNDER CONSTRUCTION. SPLICE BARS IN POSITION.
BOMB NOSE FOUND HERE
TALLBOY (M) CRATER 90 34' X 29'
JOINTS AT 17'-0" CENTRES
JOINTS OF 24'-10" CENTRES
VENTILATOR SHAFTS
28'-8"
VENTILATOR SHAFT
LINE OF CONCRETE POSTS 8" SQ. X 2'-7" HIGH AT 10'-10" CENTRES
137'-0"
ROOF PLAN
SCALE OF FEET — GROUND AND ROOF PLANS
3' CAMBER ON ROOF
NOTE:- DOTTED PORTION WAS NOT SURVEYED AT THIS POINT, BUT FOLLOWS OTHER SURVEYED POINTS.
APPROX GROUND LEVEL
SECTION A.A
3' CAMBER
VENT SHAFT
3' RISE TO CROWN
PRESUMED FINAL FLOOR LEVEL
SECTION B.B
SCALE OF FEET — FOR ABOVE SECTIONS

FIG. 9.7

COPY NO: 48

RESTRICTED

HOME OFFICE REPORT CD/SA.48
MINISTRY OF WORKS REF: 55/73/4

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Date 1980 Initials [illegible]

~~CONFIDENTIAL~~

The Safety-Cost Relationship for Certain Types of Surface and Trench Shelters

A Joint Home Office and
Ministry of Works Study

UK National Archives discovery catalogue document: HO 225/48

Note that although this is based on 3 Mev initial gamma rays from fission weapons, it is nevertheless relevant to civilian collateral damage today from the use of pure fission tactical nuclear weapons

In addition, the general approach of calculating protection for minimizing civilian casualties in nuclear war can be adapted to the more "modern" designs of thermonuclear weapons, if desired.

HOME OFFICE
SCIENTIFIC ADVISERS' BRANCH
WHITEHALL, S.W.1

1953-54

TABLE OF CONTENTS

Trench shelters

Sixteen designs of standard reinforced concrete lined trench shelters 35 ft. long by 7 ft. wide are studied by the methods summarised above for surface shelters. The designs have earth covers of 1, 2, 3, and 5 ft. and strengths of 250, 500, 1000 and 1400 lb/sq.ft. Since trench shelters are likely to be built for the most part in open spaces, the shelters have been assumed to be unshielded.

Within the limits studied the optimum trench shelter is found to be the 1400 lb/sq.ft. design with about 18 ins. of earth cover. It is possible however, that a trench designed to withstand some pressure greater than 1400 lb/sq.ft. and with 2 ft. of earth cover might give a slightly higher safety/cost rating against the nominal bomb.

H.E. attack

All the designs considered above would have about the same safety and safety/cost ratings against the minor danger of H.E. attack as against the major danger of atomic attack, and it is suggested that these shelters should be judged on their atomic ratings.

Results of the study and Conclusions

Particulars of the safety and safety/cost ratings of the optimum shelters are given in the following tables, which also include corresponding particulars for the optimum "well shielded" surface shelter if used in a moderately shielded position, and for Grade A surface and trench shelters. All these shelters are designed to withstand a blast pressure of 1400 lb/sq.ft.

Surface Shelters (Reinforced Concrete)

Shielding	Wall and roof thickness	Safety rating	Cost per seat	Safety/Cost rating
Good	12" (Optimum)	75.5	£15.5	4.87
"	24" (Grade A)	86.5	21.4	4.04
Moderate	12"	65.4	15.5	4.22
"	15" (Optimum)	75.2	16.7	4.50
"	24" (Grade A)	86.0	21.4	4.02
None (open sites)	18" (Optimum)	73.8	18.9	3.90
	24" (Grade A)	82.9	21.4	3.87

Trench Shelters ($7\frac{1}{2}$ in. R.C. roof $5\frac{1}{2}$ in. R.C. walls)

	Earth cover			
None (open sites)	18" (Optimum)	85.0	17.1	4.97
	24" (Grade A)	86.8	17.8	4.88

During the course of this study it became clear that the differences between the thicknesses of the three optimum surface shelters (evaluated for shielding angles of 68^o, 34^o and 0^o) are not so great as to suggest that consideration should be given to more than three grades of shielding. For shelters in streets, a site might be regarded as -

Open, if the shielding angle to the roof of the building on the opposite side of the street is less than 17^o;
Moderately shielded, if it is between 17^o and 51^o; and
Well shielded, if it is more than 51^o.

Some allowance might however have to be made for marked variations in the height of the buildings in the street.

PART ONE. REINFORCED CONCRETE SURFACE SHELTER

I. Introduction

1. It has sometimes been stated that a basic principle of shelter design against the atomic bomb is that the designs should be balanced; i.e. that they should provide comparable protection against blast and gamma radiation at the same distance. Put in another way it has been said that there is no point in providing protection against blast at a distance where the shelter occupants will, in any case, be killed by gamma radiation, and vice versa.

2. For a particular bomb size and height of burst this principle would be correct if the distance-risk curves for both blast and gamma radiation were of the form shown in diagram 1, i.e. if there was a sharply defined critical distance below which all shelter occupants were killed and beyond which all were safe. In practice, of course, there is no such sharply defined critical distance. Factors of bomb orientation, shielding, vagaries of blast, variations in workmanship from shelter to shelter, and variation in the resistance of people to gamma radiation result in there being a considerable distance band over which some shelter occupants are killed and some survive. The true shape of the distance-risk curve is probably as indicated in diagram 2; this was the shape of the distance-risk curves from high explosive bombs in the last war and for the total casualties from the atomic bombs at Nagasaki and Hiroshima. If the distance-risk curves from blast and from radiation are of this shape it means that, within limits, any increase in safety against either blast or radiation will result in a reduction of casualties even though it leads to an unbalanced design.

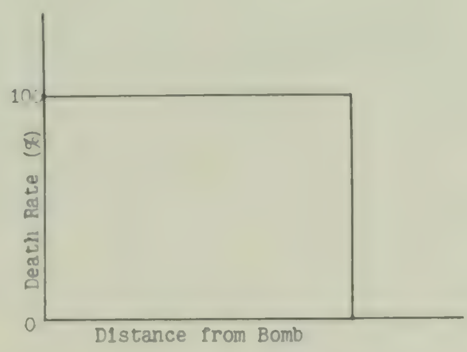

DIAGRAM 1

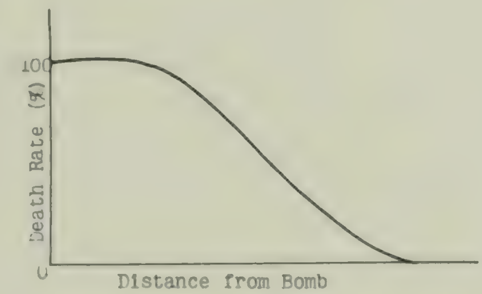

DIAGRAM 2

3. Consider a balanced shelter design in which the distance-risk curves for both blast and radiation are as shown by the full curve in Fig.1. Deaths in this hypothetical shelter for a standard population density (43.6 per acre) are calculated in Table 1, and it will be seen that they total 11,760.

TABLE 1

Deaths in Hypothetical Shelter
(Equal blast and radiation protection)

Annulus (yards)	Population	Blast		Gamma radiation		Combined	
		Death Rate	Deaths	Death Rate	Deaths	Death Rate	Deaths
0–100	280	1.0	280	1.0	280	1.0	280
100–200	850	1.0	850	1.0	850	1.0	850
200–300	1410	1.0	1410	1.0	1410	1.0	1410
300–400	1980	.97	1920	.97	1920	1.0	1980
400–500	2540	.83	2110	.83	2110	.97	2460
500–600	3110	.56	1740	.56	1740	.81	2520
600–700	3680	.26	960	.26	960	.45	1660
700–800	4240	.07	300	.07	300	.14	600
Total			9570		9570		11760

Now suppose that the gamma protection is improved to that represented by the dotted curve in Fig.1. Deaths will now be as calculated in Table 2, and it will be seen that an improvement in gamma protection which has reduced gamma deaths by 35% has reduced total deaths by 13%.

TABLE 2

Deaths in Hypothetical Shelter
(Improved protection against gamma radiation)

Annulus (yards)	Population	Blast		Gamma radiation		Combined	
		Death rate	Deaths	Death rate	Deaths	Death rate	Deaths
0–100	280	1.0	280	1.0	280	1.0	280
100–200	850	1.0	850	1.0	850	1.0	850
200–300	1410	1.0	1410	.96	1350	1.0	1410
300–400	1980	.97	1920	.80	1580	.99	1960
400–500	2540	.83	2110	.52	1320	.92	2340
500–600	3110	.56	1740	.21	650	.65	2020
600–700	3680	.26	960	.05	180	.30	1110
700–800	4240	.07	300	0	0	.07	300
Total			9570		6210		10270

4. This example clearly shows that if improved blast or gamma protection can be obtained relatively cheaply, it may well pay to incorporate it even though it results in an unbalanced design.

II. Type of Surface Shelter

5. For the purpose of this study one type of reinforced concrete surface shelter has been considered, the particulars of which are as follows:-

Internal height 7 ft; internal width 7 ft.
Internal length 35 ft. (including two closets).
Capacity: 50 persons seated (about 4.4 sq.ft./person)
Two baffled entrances, one at each end; each 2 ft. wide.

A sliding joint under the floor.
Ventilation is provided by high level inlet apertures on a scale of $1\frac{1}{2}$ sq.in. of aperture per sq.ft. of occupied floor area (excluding closets), 50% of the apertures being in each side wall, and by an equal area of low level apertures in each side wall. Two closets have separate ventilation apertures at high level.

III. Design of Surface Shelters

6. No satisfactory theory is at present available which will enable shelters (or other structures) to be designed to resist a specified atomic blast pressure. The best that can be done is to use the observations from Hiroshima and Nagasaki, which suggested that reinforced concrete structures would fail under a peak hydrostatic blast pressure of about 7 times their estimated static yield load. On this basis the surface shelters, which are of in situ reinforced concrete with roof and wall thicknesses of 12, 15, 18 and 24 ins. as shown in Fig. 2 have been designed for the following loads, at yield stresses in the steel:-

(a) A vertical superimposed load of 250, 500, 1000 and 1400 lb/sq.ft. respectively, in addition to the dead load, in each case.

(b) A horizontal superimposed load of the same intensity on each side.

7. The above loads have been considered as acting on the roof and all sides simultaneously. The cross section of each shelter has been designed as a two hinged portal frame. The moments of resistance of the roof slab and walls have been calculated from the formula given in paragraph 74 of "Air Raid Shelter".*

8. The minimum amount of main steel in each slab is 0.1% of the gross cross sectional area of the concrete, and is in accordance with the recommendations given in Codes of Practice 114. The cover to reinforcement is also in accordance with C.P. 114. The distribution steel in the roof and walls has been provided at 0.025% of the gross cross sectional area of the concrete. The distribution steel in the floor slab has been provided at 0.05% of the gross cross sectional area of the concrete.

Note: In certain designs the amount of main reinforcement required to resist the design loads is less than the minimum permissible percentage; the minimum permissible percentage is the criterion in the following cases:-

24/250	24/500	24/1000	and 24/1400
18/250	18/500	18/1000	
15/250	15/500		
12/250	12/500		

IV. Height of Burst of Bomb

9. The assumptions made with regard to height of burst have a profound influence on the optimum shelter design. For example with a high air burst (2,000 ft. as at Nagasaki) all the radiation casualties in surface shelters would be due to radiation penetrating the roof, and if this were the only height of burst to be considered it would clearly be efficient to increase the radiation protection of the roof (possibly by means of earth) and to allow the wall thickness to be determined solely by the strength requirements for blast resistance. On the other hand for a ground burst or low air burst most of the radiation strikes through the walls, which might require to be thickened for gamma protection against this height of burst.

10. It is therefore clearly essential that any proposed designs should be studied against all probable heights of burst. In order that the overall

*Issued by Ministry of Works.

merits of two designs (e.g. one good against a high burst and one good against a low burst) may be compared, it is necessary to assign probabilities to the various heights of burst. These probabilities must, in the nature of things, be quite arbitrary. The method adopted for estimating them was to invite a number of members of the staff of the Scientific Advisers' Branch, Home Office with experience of assessing the effects of a nominal atomic bomb burst at various heights to make independent estimates of the relative probabilities of bursts at heights of $\frac{3}{8}$ mile, $\frac{1}{4}$ mile, $\frac{1}{8}$ mile and ground level.

11. These independent estimates are shown in Table 3.

TABLE 3

Estimates of probabilities of heights of burst

Height of burst (miles)	Estimate (1)	Estimate (2)	Estimate (3)	Estimate (4)	Mean
$\frac{3}{8}$	.12	.15	.20	.20	.17
$\frac{1}{4}$	.38	.30	.30	.30	.32
$\frac{1}{8}$	.38	.45	.40	.30	.38
0	.12	.10	.10	.20	.13

12. Although the four estimates are in rather good agreement too much importance should not be attached to this fact since all four estimators had similar experience of assessments, and had previously discussed the relative merits of different heights of burst with one another on a number of occasions. However it does not seem to be possible to arrive at a better basis, and shelter designs will therefore be studied against bursts at $\frac{3}{8}$ mile, $\frac{1}{4}$ mile, $\frac{1}{8}$ mile and ground level, the relative probabilities of bursts at these heights being taken as 0.15, 0.35, 0.35 and 0.15.

V. Distance-Risk Relationship for Blast

13. It is clear from Section I that the exact shapes of the distance-risk curves for blast and for radiation have a considerable bearing on the overall safety of a shelter. Unfortunately there appears to be no direct way of determining the shape of this curve for blast. The shelters in the present studies have been designed at yield stresses to resist static loads equal to 1/7 of the peak hydrostatic pressure in the blast wave. It is anticipated therefore that the shelters will be seriously damaged, but will not actually collapse, at the corresponding design distances from ground zero. It is not known what percentage deaths this serious damage would cause. It is thought that the killed will probably be less than 50% and a figure of 40% has been arbitrarily assumed.*

14. In order to draw curves showing the percentage deaths at other distances it is assumed that if the pressure is 50% more than the design figure practically everyone (95%) is likely to be killed, and that if the pressure is 25% less practically nobody (say 5%) will be killed.

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* This question has been previously referred to in:-

CD/SPR/20 Appendix 4
CD/SPR/57 Appendix 11
CDJPS(EA)(48)14(Revised) Appendix 2.

15. On this basis, and from blast pressure-distance data for various heights of burst,* it is a simple matter to draw distance-risk curves for blast deaths for each of the design pressures and for each of the four assumed heights of burst. The curves for 1400, 1000 and 500 lb/sq.ft. are reproduced as Figs. 3, 4, and 5.

VI. Distance-risk Relationship for Gamma Radiation

(A) Penetration Formula

16. Previous Work. A.R.E. Report H13/51 describes a method for the accurate determination of the dose rate at the centre of a shelter, provided that the radiation arrives as a homogeneous parallel beam of known energy. By means of certain simplifying assumptions the method can be extended to cover the dose at points other than the centre, and this was done in a recent paper by the Scientific Advisers' Branch, Home Office∅, where the variation in dose across the horizontal mid-plane of a shelter due to a homogeneous parallel beam was studied. The method was laborious and of insufficient accuracy to justify its adoption for a large scale study. However, for want of anything better, certain of its results as given in CD/SA 41 Table 7, have been taken as the standard of comparison for other simpler methods.

17. Slant thickness method based on AERE formula. It is shown in CD/SA 41 paragraph 4 that for radiation of energy 3 MeV the dose in a shelter as calculated by the A.E.R.E. formula

Penetration Factor = exp (− S/6.75) where S is the thickness of the concrete in inches,

in many cases agreed well with that given by the full A.R.E. method of computation, provided that S was taken as the slant thickness of the face in the line of sight.

18. The shelter was therefore considered as divided into two portions depending on whether the line of sight to the bomb passed through the roof or wall, and the dose in each portion calculated using the appropriate slant thickness. The relative volumes of the two portions were calculated (assuming for comparison with CD/SA 41 results, a shelter 30' x 10' x 10', walls 2 ft. thick). The death rate in each portion was then calculated on the basis of linear variation between 0% killed at 300r and 100% killed at 700r.

19. It is realised that this relationship gives a somewhat lower lethality particularly for doses in the 200-400r. range than that given by the Medical Research Council. However, it is more convenient for purposes of calculation than the M.R.C. figures; it is the relationship adopted for previous atomic casualty studies, and any tendency it may have to underestimate radiation casualties should be compensated for to some extent by the overestimate resulting from the assumption that all the radiation arrives as a homogeneous beam. In fact a proportion of the radiation, the exact amount depending on the distance from the bomb, will be scattered radiation which will have a much reduced penetrating power.

20. From these death rates and relative volumes the average death rate from radiation for the shelter as a whole was calculated and the results are shown in Col. 7 of Table 4.

21. This slant thickness method allows for the scattered and unscattered radiation received from the face in the line of sight but ignores the

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*J.H. Bird "The pressure on the ground at large distances from an air burst bomb". Armament Research Establishment Memo No. 10/1950.

∅ "Gamma Ray Penetration of Grade A. Concrete Shelters. Comparison of Dosage and Casualty Estimates based on A.R.E. Report H13/51 with earlier estimates based on an A.E.R.E. formula" Report No. CD/SA 41.

scattered radiation from the face not in the line of sight, thus producing an artificially sharp demarcation in the doses in the two portions of the shelter. An attempt was made to overcome this by calculating the weighted average dose over the whole shelter and hence the average death rate. The results as shown in Table 4 column 8 did not agree as well with the CD/SA 41 "standard" results (Table 4 column 15) as the previous ones.

22. Some calculations were also done using slant thickness and figures given by Hirschfelder and Adams (*) but the results did not agree as well with the "standard" ones as those given by the A.E.R.E. formula.

23. Modified ARE Method. The shelter was again considered as divided into two portions depending on whether the line of sight was through the roof or wall. The dose at a point very close to the roof or wall could be readily calculated by the ARE method and this was taken as the dose throughout the portion of the shelter receiving its energy through that face. The average death rate from radiation based on the death rate in each portion and the relative volumes thereof, was then calculated as before - see Table 4 column 14.

24. An attempt was made to distinguish between the scattered and unscattered radiation, so as to allow for the fact that the scattered radiation from each face filled the whole of the shelter and not only the portion in the line of sight of the scattering face. To do this satisfactorily allowance had to be made for the variation in the scattered radiation across the shelter and this complicated the method unduly.

25. Method adopted. In view of its simplicity and reasonably good agreement with the so-called "standard" results the slant thickness method, the results of which are given in Col. 7 of Table 4, was adopted for all calculations of the gamma dose inside a shelter.

(B) Shielding by surrounding buildings

26. The amount of shielding by surrounding buildings may well be the most important single factor affecting gamma radiation casualties in surface shelters. For example it is shown subsequently (Tables 5 and 7 of the Appendix) that the deaths among a population of standard density (43.6/acre) all in 12 in. reinforced concrete surface shelters designed to 1,000 lb/sq.ft. and sideways on to a bomb burst at a height of $\frac{1}{8}$ mile are 22,650 if the shelters are in the open and unshielded by surrounding buildings, and only 6,780 if they are all in well shielded positions (shielding equivalent to a 50 ft. high building 20 ft. away or better). In practice all degrees of shielding from zero up to almost complete will be encountered, and since shielding has such a large influence on casualties, it is clear that, in theory, the safety-cost relationship for surface shelters ought to be determined for a very large number of shielding conditions. However the labour involved in such a comprehensive study would be prohibitive, and its results might prove impossible to apply since each amount of shielding might call for a slightly different design of shelter, giving rise to a quite unacceptable multiplicity of designs. The best that can be done appears to be to define a limited number (say three) of degrees of shielding, and to work out the safety-cost relationship of each design of shelter for each of these three degrees of shielding. This procedure does mean, however, that variations in actual shielding within each shielding class will lead to quite large variations in safety. It will be realised from the figures given later, in, for example Table 15 that these variations are so large as to swamp most of the errors likely to arise from other causes, e.g. the use of an approximate gamma penetration formula, and to some extent, therefore they justify the approximations used in other Sections.

(* Phys. Rev. 73, p.863, 1948.

TABLE 4

Shelter deaths from radiation as calculated by various methods

In all cases:-
Height of burst = 220 yards
Energy of radiation = 3 MeV
Shelter dimensions = 30' x 10' x 10' walls 2½ft. thick.

Distance from G.Z. (yd)	Position	Probability dose received through		A.E.R.E. Slant Thickness Method				Hirschfelder & Adams			Modified A.R.E. Method			Full A.R.E Method
				Killed by dose from		Average death rate from gamma radiation	Death rate based on average dose	Killed by dose from		Average death rate from gamma radiation	Killed by dose from		Average death rate from gamma radiation	Average death rate from gamma radiation
		Wall	Roof	Wall (%)	Roof (%)	(%)	(%)	Wall (%)	Roof (%)	(%)	Wall (%)	Roof (%)	(%)	(%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
600	side-on	.82	.18	30	0	25	12	41	0	34	42	0	34	28+
	end-on	1.37	1.63	"	"	14	0	"	"	19	"	"	19	6
500	side-on	.755	.245	92	0	70	52	100	0	75	100	0	75	97+
	end-on	1.02	1.98	"	"	31	0	"	"	34	"	"	34	29
400	side-on	.725	.275	100	0	72	100	100	0	72	100	0	72	100
	end-on	.91	2.1	"	"	30	10	"	"	30	"	"	30	40

+ The "standard" results in column 15 are all based on the doses in the horizontal mid-plane of the shelter. In the cases marked + the dose near the roof would have been appreciably less than the dose at the mid-plane, and thus these figures are too high for the death rate in the whole shelter.

(19908)

27. An examination of a number of typical areas in London suggests that, if all conditions of shielding have to be represented by three cases, the most representative values to use for these three cases are:-

(i) Well shielded. Shelter shielded by building 50 ft. high and 20 ft. away. Shielding angle from floor of shelter to roof of shielding building 68°.

(ii) Moderately shielded. Shelter shielded by building 20 ft. high and 30 ft. away, shielding angle 34°.

(iii) Unshielded.

28. Complete calculations of deaths for each of these three conditions of shielding have been made and the results are presented in later sections of this report. In practice it is considered that each of the three shielding angles studied should be taken as representative of a range:- Thus shelters with an actual shielding angle of more than 51° should be considered as well shielded; those with an angle of 17° to 51° as moderately shielded and those with an angle of less than 17° as unshielded.

29. Variations in the construction of the shielding building introduce yet another variable. However it is considered that this can safely be ignored. It was shown in CDJPS(EA)(48)14(Revised) that the weight of material in an ordinary British house was about the same as that in an open box (no roof or floors) with 11 in. concrete walls, and it was considered in that paper to be a satisfactory approximation to represent the shielding building by such an open box. It will be assumed in this paper that all types of shielding building (not only houses) can be represented in this way and that any shielding building can be represented by an 11 in. concrete wall with a height equal to the height to eaves level of the shielding building. For low heights of burst of the bomb the shelter may be shielded by the back wall of the house as well as by the front wall. It is therefore assumed that, in all cases, there is a second 11 in. wall of the same height as the shielding wall and situated 30 ft. behind it.

30. For ground burst bombs it is assumed that if the shelter is shielded at all (i.e. if the shielding angle is more than 17°) it is completely shielded from gamma radiation.

(C) Effect of Shelter Orientation

31. In considering the orientation (e.g. end-on, side-on or oblique) of the shelter relative to the direction of bomb burst, allowance has to be made for the following factors:-

(i) The effects of gamma radiation and blast have eventually to be combined so as to give a "safety rating" for various shelter designs.

(ii) Our knowledge of shelter strength relative to blast pressures is quite insufficient to enable us to estimate the effect of orientation on blast resistance.

(iii) The gamma radiation penetrating a shelter is, as shown in an earlier study (CD/SA 41) markedly dependent on the orientation of the shelter, being a maximum for sideways-on shelters, diminishing as the azimuth angle increases to reach a minimum at about 45°, and increasing again to another (but smaller) maximum in the end-on position.

32. Now CD/SA 41 showed that the contribution of penetration through the side walls decreased very rapidly for azimuth angles greater than about 45°. It also showed that penetration through the end walls was only important between 45° and 90°. On the basis of this limited evidence it is concluded that each wall of the shelter can therfore be regarded as being uniquely responsible for lateral protection from bombs within a 90° arc (the roof, of course, is responsible for overhead protection through the whole 360° range) and the problem of penetration through the side walls and through the end walls can be considered separately.

33. Penetration through side walls (azimuth angles from -45° to $+45^{\circ}$). It is clear that limiting the gamma study to the pure "sideways-on" (azimuth angle 0°) position would have the advantage of simplicity, but a study of the effect on the casualties of variations in azimuth angle was required to determine whether there was any risk of such a simplification invalidating the relative casualty estimates for various shelter designs.

34. To eliminate the effects of the end walls the shelter considered was assumed to be infinitely long, of square cross section (7 ft. x 7 ft) and with 18 inch walls and roof.

35. The total radiation deaths* calculated by annuli as described in the introduction were estimated for positions of the shelter such that the azimuth angles between the short axis and the direction of ground zero were 0°, 10°, 20°, 30°, and 40°. For any particular angle of elevation of the bomb the slant thickness of the side walls increases as the azimuth angle increases, and so the casualties due to the dose penetrating the side walls decreases. The slant thickness of the roof remains constant for a fixed angle of elevation of the bomb, but the fraction of the shelter which receives its radiation through the roof rather than through the side increases slightly as the shelter is rotated, and so the total "roof casualties" increase somewhat.

36. Results were calculated for each of the four standard heights of burst ($\frac{3}{8}$ mile, $\frac{1}{8}$ mile, $\frac{1}{4}$ mile, and ground level) and a weighted mean obtained by the use of the weighting factors given in para. 12. The results are presented in Table 5.

TABLE 5

Effect of orientation on unshielded 18 in. shelter

Shelter orientation	Radiation Deaths		
	Through side wall	Through roof	Total
Sideways-on (azimuth angle 0°)	7,640	2,290	9,930
Average of azimuth angles of 0° 10°, 20°, 30°, 40°	6,050	2,390	8,440
Azimuth angle 40°	3,990	2,580	6,570

37. It will be seen that, for an azimuth angle of 40° deaths are 34% less than in the sideways-on position, but when the results are averaged over the 5 positions considered deaths are only 15% less than in the sideways-on position.

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*Here and elsewhere in this paper, "total deaths" are used as a convenient measure of such factors as effect of orientation, effect of shielding etc. When, as here, they are calculated for a particular set of conditions (e.g. a single azimuth angle) they represent a purely hypothetical case and their value is comparative rather than absolute. For example the 9930 deaths shown in Col. 3 of Table 5 would only occur if a standard population density (43.6 per acre) were all in unshielded 18" surface shelters strong enough to resist blast at all ranges where any occupants survived the radiation and if all the shelters were oriented so as to be exactly sideways on to the burst. If 15, 35, 35 and 15 bombs burst respectively at heights of $\frac{3}{8}$ mile, $\frac{1}{4}$ mile, $\frac{1}{8}$ mile and ground level under these conditions, then it is expected that the average deaths would be 9,930.

38. It is clear from Table 5 that, for unshielded shelters orientation is quite an important factor in casualty estimates. However, surface shelters are likely to be used mainly in built-up areas and would, in general, be appreciably, shielded by neighbouring buildings. For shielded shelters, the effect of orientation is likely to be less important than for unshielded shelters since, as the azimuth angle increases, the increase in the slant thickness of the shelter wall will be offset by a reduction in the shielding angle. The results, calculated on the same basis as those in Table 5, for a number of shielded shelters are summarised in Table 6.

TABLE 6

Effect of orientation on shielded 18 in. shelter

Shelter orientation	Shielding conditions	Radiation Deaths		
		through side wall	through roof	total
Sideways-on (0°) Azimuth angle 40°	(20 ft. high building (30 ft. from shelter	1740 1680	2290 2980	4030 4260
Sideways-on (0°) Azimuth angle 40°	(20 ft. high building (20 ft. from shelter	1470 580	2270 2580	3740 3160
Sideways-on (0°) Azimuth angle 40°	(50 ft. high building (20 ft. from shelter	60 20	1100 1690	1160 1710

39. It will be seen from Table 6 that, for shielded shelters, changes in orientation may either increase or decrease the deaths somewhat. However, this variation with orientation is trivial when compared with changes due to shielding, the errors from which source are bound to be fairly large due to the practical necessity of assuming a limited number of standard shielding conditions. Thus it was decided that over the range of azimuth angles from -45° to +45° the effect of orientation could be ignored, and that within this range estimates of casualties due to gamma radiation could be based solely on shelters sideways-on to the burst.

40. Penetration Through End walls (azimuth angles from 45° to 135°). It was shown in CD/SA 41 that, for unshielded shelters with side and end walls of the same thickness, shelter occupants were better protected in the end-on than in the side-on position. For the present series of shelter designs, with entrances protected by baffle walls at both ends, the occupants of an unshielded shelter are very much better protected in the end-on than in the side-on position. However the position is complicated by shielding; although a street surface shelter may be well shielded by surrounding buildings against side-on attack, it is likely to be quite unshielded in the end-on position, and therefore for shelters well shielded in the side-on position, the end-on position may be the most dangerous. This is illustrated in Table 7 which compares the radiation deaths in the end-on and side-on position for three different degrees of side-on shielding (as before the figures given are the weighted means for the 4 standard heights of burst)

TABLE 7

Comparison of Radiation Deaths in the End-on and Side-on Positions for 18" Shelter

Shielding condition of sides	Radiation deaths side-on	Radiation Deaths. End-on		
		through wall	through roof	Total
Unshielded	9830	1700	3170	4870
Shielding angle 34°	4030			
Shielding angle 68°	1450			

41. It will be seen that the radiation deaths in the end-on position are about the same as for the moderately shielded side-on shelter. It will also be seen that the majority of the end-on deaths are through the roof; this means that it is not unreasonable to take the pure end-on position (azimuth angle 90°) as representative of the whole end-on range (azimuth angles from 45° to 135°) since although deaths through the end wall will decrease with any change in azimuth angle from 90°, deaths through the roof will remain approximately constant. It was therefore decided that the pure end-on attack (azimuth angle 90°) could be taken as representative of the whole end-on range.

D. Summary of distance-risk rates for radiation

42. Tables 1, 2, 3 and 4 of the Appendix present similar data on distance-risk rates for gamma radiation to that given in Figs. 3-5 for blast. In this case it is more convenient to present the data in tabular rather than graphical form, since it was calculated in this way and it is in this form that it is required for subsequent combination with the blast risk rates. It will be seen that, for the reasons discussed in the preceding sections, separate figures are given for three different degrees of shielding in the side-on position, and for unshielded shelters in the end-on position.

VII. Deaths from Blast and Radiation Combined

43. It is now necessary to combine the blast and radiation risks for each type of shelter, each position (end-on or side-on), each degree of shielding, and each height of burst by the method discussed in the introduction. The results of this combination are given in Tables 5, 6 and 7 of the Appendix for unshielded, moderately shielded and well shielded shelters repectively. The figures given in these Tables are summarised in Table 8 which brings out very clearly the importance of shielding; deaths in a well-shielded 12" shelter may be less than in an unshielded 18" shelter.

TABLE 8

Summary of Deaths in Surface Shelters

Shielding Conditions	Design blast pressure (lb/sq.ft)	Deaths averaged over height of burst and shelter orientation			
		12" Shelter	15" Shelter	18" Shelter	24" Shelter
Unshielded (Shielding angle less than 17°)	No. blast deaths	14,700	10,600	7,400	3,800
	1,400	14,700	11,200	8,100	5,300
	1,000	14,800	11,600	9,000	-
	500	17,900	16,000	-	-
Moderately Shielded (Shielding angle 17° to 31°)	No. blast deaths	10,300	7,100	4,500	2,400
	1,400	10,700	7,700	5,600	4,300
	1,000	11,000	8,300	6,800	-
	500	14,800	14,000	-	-
Well Shielded (Shielding angle more than 51°)	No. blast deaths	6,500	4,500	3,200	1,600
	1,400	7,600	6,000	5,100	4,200
	1,000	8,400	7,200	6,500	-
	500	14,100	13,800	-	-

VIII. Safety-Cost Relationship

44. A good measure of the value of any shelter is clearly its "cost per life saved". To put the results on this basis it is necessary to subtract the calculated deaths for the various type of shelters given in Table 8 from what the deaths would have been if there had been no shelters. For this the figure of 31,000 given in CDJPS(EA)(48)14(Revised) for a population all in houses will be used. Admittedly this figure relates to only one height of burst ($\frac{1}{8}$ mile) whereas the figures in Table 8 are weighted means for four heights of burst. However the exact value assumed will not seriously affect the results.

45. For convenience in the presentation of the results the "lives saved" will be expressed as a percentage of the deaths among a population all in houses (31,000) and this percentage will be called the SAFETY RATING for the shelter. On this scale a completely bomb proof shelter (lives saved 31,000) has a rating of 100 and a house (lives saved 0) a rating of zero. Table 9 summarizes the "safety ratings" calculated in this way from the deaths given in Table 8.

TABLE 9

Safety Ratings of Surface Shelters

Shielding Conditions	Design Blast Pressure (lb/sq.ft.)	Safety Rating			
		12" shelter	15" shelter	18" shelter	24" shelter
Unshielded (shielding angle less than 17°)	No. blast deaths	52.16	65.8	76.1	87.7
	1400	52.5	63.8	73.8	82.9
	1000	52.2	62.6	71.0	-
	500	42.1	48.4	-	-
Moderately Shielded (Shielding angle 17° to 51°)	No. blast deaths	66.7	77.1	85.5	92.3
	1400	65.4	75.2	81.9	86.0
	1000	64.4	73.3	78.0	-
	500	52.2	54.8	-	-
Well shielded (Shielding angle more than 51°)	No. blast deaths	79.0	85.5	89.6	94.8
	1400	75.5	80.6	83.5	86.5
	1000	72.9	76.8	78.9	-
	500	54.5	55.5	-	-

46. The costs of the various types of shelter are summarised in Table 10 and plotted against the appropriate safety ratings in Fig. 6. These costs are based on Grade A labour rates and prices of materials ruling at February, 1952, for construction on level sites in virgin ground and exclude the cost of any reads, paths and site work generally. The cost of electric wiring is included, but not the cost of bringing in the service mains. The cost of seating and internal fittings is not included.

TABLE 10

Cost per Head of Surface Shelters

Thickness of Concrete	Design Blast Pressure (lb/sq.ft.)	Cost per Head (£)	Weight of steel per head (lb.)
12"	1400	15.5	45.0
	1000	15.2	36.8
	500	14.6	23.1
15"	1400	16.7	44.4
	1000	16.4	31.6
	500	16.0	28.5
18"	1400	18.9	43.4
	1000	18.5	34.8
24"	1400	21.4	48.2

47. It will be noted that, in Tables 8 and 9 figures are given for a design blast pressure sufficient to ensure that deaths occur from gamma only (i.e. that there are no blast deaths). The actual design blast pressure needed to ensure this would vary with the thickness of the shelter and the amount of shielding, but in many cases would be little more than 1400 lb/sq.ft. In all

cases the curves of Fig. 6 for the various thicknesses of concrete have been extended beyond the highest calculated point (1400 lb/sq.ft. pressure) so as to be asymptotic to this "all gamma" case, but it must be pointed out that the actual shape of the curves between the "1400" point and this asymptotic value is largely a guess.

48. From the curves for each concrete thickness plotted in Fig. 6 an envelope curve for each degree of shielding can be drawn indicating the most efficient design, and this has been done in the figure. It is clear that any shelter represented by a point lying below and to the right of these envelope curves is inefficient since its "cost per life saved" is higher than for a shelter lying on the curve. Thus it can be seen (interpolating where necessary and assuming that the "guessed" shapes of the curves above 1400 lb/sq.ft. are correct), that for unshielded shelters the most efficient design for a shelter 12 ins. thick would be one designed for about 800 lb/sq.ft. and for a shelter 15 ins. thick one designed for 100 lb/sq.ft. For the 18" and 24" shelters it appears that efficiency could only be secured by designing them for greater blast pressures than 1400 lb/sq.ft. For moderately shielded shelters the most efficient design for a shelter 12 ins. thick would be one designed for about 900 lb/sq.ft., and for a shelter 15 ins. thick, one designed for about 1400 lb/sq.ft. Thicker shelters should be designed for higher blast pressures than 1400 lb/sq.ft. to be efficient. For the well shielded shelters only the 12"/1400 lb./sq.ft. design is efficient, all the other thicknesses should be designed for a higher blast pressure than 1400 lb/sq.ft. These results could, of course have been obtained directly from Tables 9 and 10 without recourse to the curves. The most efficient shelter in each group is that which has the greatest "safety/cost rating" (i.e. the lowest cost per life saved per bomb) and these will be found to correspond with the designs listed above. An alternative way of presenting these results is shown in Fig. 7 where the safety/cost ratings are plotted against thickness for the various designs and conditions of shielding. These curves illustrate where the various maxima occur rather more clearly than does Fig. 6.

49. One other important conclusion is suggested by the curves of Fig. 6. It is that for each degree of shielding, there is a minimum standard of shelter below which it does not pay (in terms of cost per life saved) to go. This minimum is given by the point at which the tangent from the origin touches the appropriate envelope curve, i.e. the point at which the overall safety rating per £ per person is a maximum; this again is the safety/cost rating and is the true measure of the safety and economy of any particular shelter design. It will be seen from Fig. 6 that the shelters with the highest safety/cost rating are as follows:-

<u>Unshielded</u> about 18 ins. thick designed for about 1400 lb/sq.ft; safety/cost rating 3.86.

<u>Moderately Shielded</u> About 15 ins. thick designed for about 1400 lb/sq.ft; safety/cost rating 4.5.

<u>Well Shielded</u> About 12 ins. thick designed for about 1400 lb/sq.ft; safety/cost rating 4.85.

50. Since the adoption of the shelter with the highest safety/cost rating yields the best return in terms of cost per life saved, and since there seems to be little prospect, in the time likely to be available for building shelters, of building shelters of a higher standard than this, this standard will be referred to subsequently as the "optimum" standard or design.

51. A simple numerical example will illustrate the advantages of adopting this optimum standard. The cost/head of the optimum design for moderately shielded shelters (15"/1400 lb/sq.ft.) is £16.7 and the safety rating 75.2. In other words this shelter would save 75.2% of the casualties in any area where it was used and which was attacked with an atomic bomb. For the same cost (£16.7 per head) 24"/1400 lb/sq.ft. shelters could clearly be provided for $\frac{16.7 \times 100}{21.4} = 78\%$ of the inhabitants leaving the remainder with no shelter at all. The average safety rating of the population under these conditions would be $0.78 \times 86.0 = 67.0$. The safety rating for this combination is therefore 8.2% lower than for the optimum shelter i.e. casualties would be 8.2%

higher. Alternatively suppose resources are not sufficient to provide the optimum shelter for everyone, and that the sum available is only £14.6 per head. For this everyone could be provided with 12"/500 lb/sq.ft. shelters with a safety rating of 52.2. Or $\frac{14.6 \times 100}{16.7}$ = 87.5% of the population could be provided with optimum shelters (15"/1400 lb/sq.ft.) and leave the rest without shelter. The average safety rating of the population for this case would be .875 x 75.2 = 66.0. Thus here again it has paid in terms of lives saved to use the optimum standard even though it means leaving some people without shelter. The safety ratings given above can of course be converted directly into lives saved per bomb for any area in which the population density is known. Thus for a single bomb on an area of standard density (43.6 per acre) an increase in safety rating from 52.2 to 66.0 means a saving of 13.8% of 31,000 or 4,300 lives.

52. This conclusion, that there is an optimum standard for shelters, is of the utmost importance. It means that if only limited funds are available for building shelters it will pay better (in terms of lives saved) to build a limited number of shelters of the optimum standard, rather than to attempt to provide everyone with shelter of some lower standard. Of course if funds are sufficient to provide everyone with shelter of better than the optimum standard, so much the better, but this seems to be a rather unlikely eventuality.

IX. Possible use of Thinner Roofs Supplemented by Earth

53. So far in this study shelters have been considered with walls and roof of equal thickness. However in designing a shelter, one of the problems is to find the best possible allocation of the available material as between walls and roof. Assuming that the walls and roof have equal mechanical strength (i.e. equal blast resistance), the material should clearly first be concentrated on whichever is letting through the most gamma radiation. Thus against a ground burst the sides and end should be thickened at the expense of the roof, while against a 3/8 mile burst the reverse should be done.

54. Combined blast and radiation deaths have been calculated, and are shown in Table 11 below, for moderately shielded shelters with a static strength of 1400 lb/sq.ft. and 12" walls, with varying roof thicknesses.

TABLE 11

Deaths for different roof thicknesses, 12" walls

Height of Burst	12" roof	15" roof	18" roof	21" roof	24" roof	No gamma deaths through roof
0 miles	10,780	10,780	10,780	10,780	10,780	10,780
$\frac{1}{8}$ mile	9,820	8,900	8,860	8,810	8,810	8,810
$\frac{1}{4}$ mile	13,040	11,090	9,800	9,130	8,770	8,640
$\frac{3}{8}$ mile	7,580	5,030	3,090	1,430	340	60
Weighted Mean	10,750	9,370	8,610	8,110	7,820	7,730

55. Using Tables 11 and 8 and assuming for the present purpose that two shelters with the same volume of concrete will cost the same, the efficiency of thickening the roof only, can be compared with that of thickening the roof and walls uniformly. This has been done in Fig. 8 in which safety ratings are plotted against concrete volume, for various combinations of roof and wall thickness.

56. It will be seen that thickening the roof only is slightly advantageous for small changes and definitely disadvantageous for large ones. The curves suggest that the ideal is to have the roof about 3 or 4 inches thicker than the walls, but the gain is a small one. However this conclusion depends very critically on the weighting of the various heights of burst. If more weight were given to the greater heights, particularly to the $\frac{3}{8}$ mile there

would be a large gain from thickening the roof rather than the walls. Conversely if more weight were given to the ground level burst it would probably pay to have the walls thicker than the roof.

57. Earth is cheaper than concrete, and an alternative to thickening the roof concrete is to pile earth, held in position by a parapet wall, on top of the shelter.

58. The cost of various thicknesses of earth with parapets of sand bags, hollow concrete blocks, brick walls and in situ concrete have been determined and are given in Table 12.

TABLE 12

Costs of Earth or Sand on Roofs of Surface Shelters

Construction of parapet wall to retain earth or sand	Height of wall and fill (in.)	Cost per shelter size 43' x 9' (£)	Cost per inch of fill (£)
Sandbags	5	14	2.8
	10	28	2.8
	15	48	3.2
	20	68	3.4
Hollow concrete blocks 18" x 9" x 9"	9	27	3.0
	18	51	2.8
Dwarf brick wall in mortar	6	18	3.0
	12	35	2.9
	18	60	3.3
Concrete curb	6	32	5.3
	12	61	5.1
	18	91	5.1

59. It will be seen that the cheapest type of parapet depends on the height of fill, but that all heights up to 18" can be provided for a cost of £2.8 per inch of fill. The corresponding cost for each extra inch thickness of concrete on the roof can be deduced from Table 10 to be about £7 per inch or, allowing for the fact that $1\frac{1}{2}$ inches of earth are required to give the same radiation protection as 1 in. of concrete, about 1.7 times the cost of earth fill.

60. Table 13 shows the improvement in the safety-cost relationship that could be achieved by various thicknesses of earth fill on the roof of a 12"/1400 lb/sq.ft. surface shelter.

TABLE 13

Effects of Earth Fill on Roof of 12"/1400 lb/sq.ft. Shelter

Thickness of earth fill (ins.)	Cost/Head (£)	Safety Rating	Safety Rating per £ per head
0	15.5	65.4	4.22
$4\frac{1}{2}$	15.75	69.8	4.43
9	16.0	72.2	4.51
$13\frac{1}{2}$	16.25	73.8	4.54
18	16.5	74.8	4.53

61. It will be seen that, in this case, it pays to add up to about $13\frac{1}{2}$" of earth fill on top of the shelter.

62. Calculations similar to the above have not been made for other shelter designs; in particular they have not been made for the optimum design of moderately shielded shelter (15"/1400 lb/sq.ft.) However it seems fairly clear that where the basic concrete design is thicker it will pay to add rather less earth - probably about 10 ins. for a 15" shelter.

63. Since earth is cheaper than concrete, and since all the present series of designs are somewhat under-reinforced (the reinforcement in the roof of the 1"/1400 lb/sq.ft. design is only 0.25%) it is clear that the possibility exists of producing a more efficient design by reducing the thickness of the roof concrete to perhaps as little as 6 to 8 ins. and making up the balance of the required roof thickness with earth. However the true relative contributions to blast resistance of the steel and the concrete in a reinforced concrete slab are at present uncertain, and with a thinner roof there might be some difficulty in ensuring adequate corner strength to resist racking forces. For the present, therefore, designs should probably be based on equal roof and wall thicknesses, but the possibility of reducing the roof thickness should be re-examined when further test data on the behaviour of reinforced concrete under atomic blast are available.

X. The effect of less penetrating radiation

64. The penetration formula used hitherto in this paper for the calculation of distance-risk rates for gamma radiation corresponds to an energy of about 3 MeV. There is, however, some evidence that the incident radiation may have a lower penetrating power, corresponding to an energy of less than 3 MeV. Some of the calculations have therefore been repeated using, for convenience, penetration factors given by Hirschfelder and Adams for radiation of energy 1 MeV. These are considerably lower than for 3 MeV radiation; for instance, for 12 inches of concrete the penetration factor is reduced to about a quarter of its former value if the energy is reduced from 3 to 1 MeV, and for 24 inches of concrete it is reduced to one-tenth of its previous value.

65. The distance-risk rates for a 12" shelter both unshielded and with medium shielding are shown in Table 8 of the Appendix for radiation of energy 1 MeV, and the deaths resulting from combining the blast and radiation risks in Table 9 of the Appendix. The latter figures are summarised in Table 14 which also shows for comparison the figures taken from Table 8 for 3 MeV radiation and the deaths which would result if the shelter were subjected to blast alone. Figures for shelters thicker than 12 ins. have not been calculated for 1 MeV radiation since even with the 12 in. shelters the majority of the deaths are due to blast and the potential gain from thicker shelters is very small.

TABLE 14

Comparison of deaths in 12" surface shelters for 3 MeV and 1 MeV radiation

Shielding conditions	Design Blast pressure	Deaths in 12 in. shelter averaged over height of burst and shelter orientation	
		Assuming 3 MeV radiation	Assuming 1 Mev radiation
Unshielded	No. blast deaths	14,700	5,000
	1,400	14,700	6,300
	1,000	14,800	7,500
	500	17,900	14,000
Moderately shielded	No. blast deaths	10,300	2,900
	1,400	10,700	4,600
	1,000	11,000	6,200
	500	14,800	13,500
So well shielded that deaths are due to blast only	No. blast deaths	-	-
	1,400	4,000	4,000
	1,000	5,700	5,700
	500	13,400	13,400

Table 14 shows clearly the enormous influence on deaths of the assumption made as to energy of radiation particularly in strong, unshielded shelters. For example the 14,700 deaths in unshielded 1400 lb/sq.ft. shelter calculated for 3 MeV radiation are reduced to only 6,300 if the radiation is of 1 MeV energy.

66. Fortunately, however, the assumed energy of the radiation does not greatly affect the choice of design. This is shown in Table 15 which compares the safety/cost rating of the various thicknesses of shelters against 3 MeV radiation with those of the 12 in. shelter against 1 MeV radiation.

TABLE 15

Efficiencies of surface shelters against 3 MeV and 1 MeV radiation

Shielding	Design Blast pressure (lb/sq.ft.)	Safety/cost rating of shelter				
		1 MeV Radiation	3 MeV radiation			
		12" Shelter	12"	15"	18"	24"
Unshielded	1400	5.14	3.39	3.82	3.91	3.87
	1000	4.99	3.44	3.83	3.84	
	500	3.75	2.88	3.11	-	-
Moderately Shielded	1400	5.50	4.22	4.50	4.33	4.02
	1000	5.26	4.23	4.47	4.21	-
	500	3.86	3.58	3.52	-	-

67. It will be seen that, for the softer radiation the design with the highest safety/cost rating for shelters 12ins. thick is one for at least 1400 lb/sq.ft. for both unshielded and moderately shielded conditions. For the 3 MeV radiation considered earlier the corresponding figures were 800 lb/sq.ft. for unshielded and 900 lb/sq.ft. for moderately shielded 12 in. shelters.

XI. The Effect of Bigger Bombs

68. All the results which have so far been given in this paper refer to a nominal bomb. However it is uncertain what size or sizes of bombs the enemy will use against us and since the relative importance of blast and radiation is dependent on the size of the bomb, it is essential to see how our conclusions would be affected by variations in bomb size. Although bombs smaller than nominal may be used against tactical targets, they would not appear to be very efficient for use against cities and only bombs larger than nominal will therefore be considered. It is impossible to specify any ultimate upper limit of size for atomic bombs, but by studying the effects of an 8N bomb a measure should be obtained of the influence of bomb size on results.

69. The deaths in moderately shielded surface shelters have therefore been calculated for an 8N bomb by the methods used earlier and are given in Table 16 for four heights of burst of $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$ and 0 miles. These four heights of burst correspond to the four standard heights given in para. 10 increased by the scale factor of 3 W

TABLE 16

Deaths in Moderately Shielded Surface Shelters from 8N bomb

Height of burst (miles)	1,000 lb/sq.ft. 12"	15"	18"	1400 lb/sq.ft. 12"	15"	18"	No. blast deaths 12"	15"	18"
$\frac{3}{4}$	9,200	5,600	3,200	8,800	4,000	800	8,800	4,000	800
$\frac{1}{2}$	29,600	26,000	25,600	26,800	19,600	17,600	26,000	16,000	12,000
$\frac{1}{4}$	29,600	28,400	27,600	26,800	23,600	22,400	24,800	20,400	16,400
0	32,400	30,000	29,600	28,400	24,800	23,600	18,000	13,600	10,800
Weighted Mean	27,200	24,400	23,600	24,400	19,600	17,600	21,600	15,600	11,600

70. Comparing these figures with the corresponding ones of Table 6 of the Appendix for the nominal bomb it will be seen that in all cases the deaths from the 8N bomb are less than 4 times those for the nominal bomb. Although blast deaths increase as the two-thirds power of the bomb size (i.e. a factor of 4 for the 8N bomb), radiation deaths increase more slowly with increasing bomb size, and therefore total deaths are less than four times those for the nominal bomb.

71. In order to convert these deaths into safety ratings we should strictly speaking calculate the deaths in houses for an 8N bomb. However since 30,000 of the 31,000 deaths in houses from the nominal bomb are due to blast we cannot be much in error if we take the figure for the 8N bomb as 124,000 since it must lie between the limits of 120,000 and 124,000. The safety ratings for the moderately shielded surface shelter have therefore been calculated on this basis and are given in Table 17.

TABLE 17

Safety ratings for moderately shielded surface shelters for 8N bomb

Design blast pressure (lb/sq.ft.)	Safety Rating		
	12" shelter	15" shelter	18" shelter
No blast deaths	82.4	87.5	90.6
1400	80.4	84.3	85.8
1000	78.2	80.3	81.0

72. These safety ratings are plotted against cost (from Table 10) in Fig. 9 which also shows the envelope curve for the nominal bomb (From Fig. 6). An examination of Fig. 9 draws attention to the following points:-

(i) The safety ratings of all the shelters are considerably higher against the 8N than against the nominal bomb.

(ii) The 12"/1400 lb/sq.ft. shelter is the optimum design against the 8N bomb (i.e. the design for which the tangent from the origin touches the envelope curve).

(iii) The 15" and 18" shelter should be designed for a higher blast pressure than 1400 lb/sq.ft.

XII. Conclusions

73. In heavily built up areas surface shelters are often the main alternative to basement shelters, trench shelters being ruled out for lack of space. In such areas the surface shelters are likely to be well or moderately shielded. In less heavily built up areas, where surface shelters would be unshielded, it should normally be possible to replace them by trench shelters, which are shown subsequently (Part II) to be considerably more efficient.

74. The most important shielding conditions for surface shelters are therefore the well and moderately shielded cases, and surface shelters should not be built in unshielded positions if trench shelters can be constructed.

75. Shelters in Well Shielded Positions. It is shown in Section VIII that for the nominal bomb and 3 MeV radiation the 12"/1400 lb/sq.ft. is the optimum design for well shielded shelters. For larger bombs or for softer radiation it seems probable that a shelter of less thickness than 12 ins. and greater strength than 1400 lb/sq.ft. would be more efficient. However considerations of protection from H.E. fragments and psychological considerations (the minimum standard in the last war was 12 ins. and the public would consider that if this was required against H.E. something at least as thick was required against atomic bombs) probably rule thinner shelters out of consideration.

76. However even for the nominal bomb and 3 MeV radiation Fig. 6 suggests that it might pay to design the 12 ins. shelter for a rather greater load than 1400 lb/sq.ft. With the prospect of larger bombs and/or softer radiation the efficiency of higher strength designs should perhaps be explored.

77. Shelters in Moderately Shielded Positions. It is shown in Section VIII and Fig. 6 that for the nominal bomb and 3 MeV radiation the 15"/1400 lb/sq.ft. is the optimum design for moderately shielded shelters. However Section XI shows that for an 8N bomb the 12"/1400 lb/sq.ft. is the optimum design and Section X gives practically the same result for 1 MeV radiation. Moreover the advantages of using the same design for both well and moderately shielded positions are obvious. It is therefore recommended for present planning that the 12"/1400 lb/sq.ft. design should also be adopted for moderately shielded positions. If future tests confirm that the energy of the radiation is as high as 3MeV then this choice should be re-examined.

78. Shelters in Unshielded Positions. Calculations for larger bombs and softer radiation have not been made for unshielded shelters, since, as stated above, trenches should, wherever possible, be constructed in preference to surface shelters in unshielded positions. Where this is impossible the optimum design for the nominal bomb and 3 MeV radiation - the 18"/1400 lb/sq.ft. design - should be used. Although it can be argued that the possibility of larger bombs and softer radiation might justify the adoption of a thinner shelter it is considered that the adoption of the more expensive shelter is justified since in doubtful cases it may help to influence local authorities and others to use trench shelters which give much better protection for about the same cost.

79. Possible use of thinner roofs supplemented by earth. Earth is cheaper than concrete and it is shown in Section IX that in the case of the nominal bomb and 3 MeV radiation, the safety/cost rating of the 12"/1400 lb/sq.ft. design for moderately shielded shelters could be improved somewhat by the addition of about 1 ft. of earth. A further possibility, which was not studied in detail in Section IX would be to reduce the roof thickness to 6 or 8 ins. of concrete with the balance of the required thickness provided by earth. This might well provide rather greater safety at rather lower cost then the standard 12"/1400 lb/sq.ft. design recommended above for well and moderately shielded shelter. However the improvement could not be large and would be dependent on the possibilities of designing a thinner slab to carry 1400 lb/sq.ft. without an undue increase in steel content and of ensuring adequate corner strength to resist racking forces. These possibilities should therefore be examined when future data are available on the behaviour of reinforced concrete under atomic blast.

PART TWO

REINFORCED CONCRETE TRENCH SHELTER

I. Type of Trench Shelter

80. For the purpose of this study one type of in-situ reinforced concrete lined trench shelter has been considered, the particulars of which are as follows:-

Internal height 7 ft; internal width 7 ft.
Internal length 35 ft. (including two closets)
Capacity: 50 persons seated.
Stepped entrance at one end; vent shaft and emergency exit at far end.
The shelters are sunk sufficiently for the volume of excavated earth to supply the required volume of earth cover.
The high level ventilation outlet is provided on a scale of $2\frac{1}{2}$ sq.in. of aperture per sq.ft. of occupied floor area (excluding closets). The two closets are close to the ventilation outlet.

II. Design of Trench Shelters

81. The trench shelters are of in-situ reinforced concrete and have been designed in the first instance at normal stresses for peace-time loading. The peace-time superimposed load has been taken at 50 lb/sq.ft.

82. The roof slab and walls were then examined and additional steel provided where necessary to ensure that at yield stresses in the steel the moment of resistance at any point should not be less than the bending moment due to a superimposed load on the ground equal to 250, 500, 1000 and 1400 lb/sq.ft. respectively, in addition to the dead loads, in each case. The bending moment at each point has been taken as being equal to the free bending moment at that point reduced by the value of the restraint moment provided by the steel at yield stress at the corners of the shelter. The moment of resistance has been calculated from the formula given in paragraph 74 of "Air Raid Shelter". The loads due to the superimposed blast pressures have not been distributed across the floor slab. The minimum amount of main steel and cover to reinforcement comply with the recommendations of C.P.114.

83. The maximum amount of main steel is in accordance with the recommendations given in paragraph 74 of "Air Raid Shelter".

84. Distribution steel has been provided at 0.05% of the gross cross sectional area of the concrete.

85. Details of the various designs are given in Fig. 11

III. Outline of Method of Calculating Safety

86. The general method for determining the safety-cost relationship for trench shelters is the same as that described in Part One for surface shelters and is based on the same assumptions regarding distance-risk rates for blast deaths (with the addition of a 250 lb/sq.ft. blast pressure design - Fig. 10), penetration and lethality of the gamma radiation, and the likelihood of heights of burst of 0, $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{3}{8}$ miles. However, since trench shelters would most usually be sited in relatively open spaces such as parks and city squares, it is not necessary to consider the effect of various degrees of shielding and it is assumed in this study that all trench shelters are unshielded.

87. The main difference in the method of calculating safety ratings for surface and trench shelters is that for the former the mean of the number of lives saved with shelters in the end-on and sideways-on position is used, whereas for trench shelters it is sufficient to consider only the end-on position. The reason for this is explained in the following section.

IV. Gamma penetration of end-on shelters

88. The excavation necessary to give trenches 3 ft. or more of earth cover means that they are completely sunk, whereas those with 1 or 2 ft. of earth cover are only partially sunk. No matter which design of trench is considered, it can be shown that radiation meeting the end or side of the trench will, in general, have passed through a much greater thickness of earth than that meeting the roof. This suggests that it may be possible to neglect, at any rate for the initial calculations, the radiation entering the trench through the side or end, and to consider only that entering through the roof of an infinitely long trench in the end-on position. It is clear that for the completely sunk trenches these assumptions of infinite length and end-on position represent the worst case, since for any other position or length of the trench only a portion of it would be filled by radiation passing through the roof, the remainder being occupied by radiation of much lower intensity which has passed through the side or end. This "worst case" condition probably also holds for the trench shelter with only 1 or 2 ft. of earth cover, but the shape of the earth banking over the portion of the side walls above the normal ground level is such that it is necessary also to investigate the side-on position to make sure that this is so.

89. The distance-risk rates for gamma radiation penetrating the roof of an end-on infinitely long trench are given in Table 10 of the Appendix. These rates are based on the assumption that the fraction of the radiation penetrating soil of depth (d) is the same as that penetrating a concrete slab of thickness two thirds (d). The results of combining the radiation and blast risks are given in Table 11 of the Appendix, and these figures are summarised in Table 18 below.

TABLE 18

Summary of Deaths in Trench Shelters
(shelters end-on; infinite length; unshielded)

Earth Cover (ft.)	Roof (concrete) thickness (ins.)	Blast strength (lb/sq.ft.)	Deaths averaged over all heights of burst: Combined Blast and gamma	Blast only
1	7.5 (assumed)	No blast deaths	4,900	0
	7.5	1400	6,000	4,000
	6	1000	7,500	5,700
	5	500	13,600	13,400
	5	250	30,500	30,500
2	7.5 (assumed)	No blast deaths	1,900	0
	7.5	1400	4,100	4,000
	6	1000	5,900	5,700
	5	500	13,400	13,400
3	7.5 (assumed)	No blast deaths	550	0
	7.5	1400	4,000	4,000
	6	1000	5,700	5,700
	6	500	13,400	13,400
5	7.5 (assumed)	No blast deaths	0	0
	7.5	1400	4,000	4,000
	6.5	1000	5,700	5,700

90. This Table shows clearly that except for trenches with only 1 foot of earth cover and of 1,400 or 1,000 lb/sq.ft. design blast pressure the deaths are all or nearly all attributable to blast rather than gamma radiation.

91. Thus on comparing the figures of Table 18 for total deaths with those for surface shelters (Part One Table 8) it is not surprising to find that they are much lower even than those for well shielded surface shelters, since in the latter there would always be some radiation deaths.

92. There is no need to consider any position other than end-on for shelters with 3 or 5 feet of earth cover since any diminution in the gamma radiation penetrating the shelter would not alter the number of deaths which even in the end-on or "worst gamma case" position depends only on the design blast pressure. For these shelters the deaths are in fact independent of the orientation and also of the shelter length.

V. Gamma penetration of side-on shelters

93. As stated previously it is necessary to study the sideways-on position for the trenches with only 1 or 2 feet of earth cover since for low heights of burst there may be certain positions of the bomb relative to the shelter such that the equivalent concrete slant thickness of the upper portion of the wall and its covering soil is less than the slant thickness through the roof and its covering soil. In the case of a ground burst bomb it can be assumed that radiation can only enter through the portion of the shelter wall above ground level, and that for the whole of this portion the earth covering has only the minimum thickness as measured horizontally from the top of the shelter. The total combined blast and radiation casualties are shown in Table 19, for a shelter with 1 foot of earth cover.

TABLE 19

Casualties due to a ground burst bomb;
trench shelters in the sideways-on position

Earth Cover (ft.)	Wall (concrete) thickness (in.)	Design Blast Pressure (lb/sq.ft.)	Deaths	
			Combined blast and gamma	Blast only
1	5	1400	5,440	5,190
	5	1000	7,000	6,950
	5	500	11,270	11,270
	5	250	23,100	23,100

94. Thus even when the calculations are based on the minimum thickness of earth cover there is little difference, and that only at the higher design blast pressures, between the number of deaths due to both blast and gamma radiation and that due to blast alone. Hence if an average value for the thickness of the earth cover were used any difference between these figures would be negligible. For any position of the shelter other than end or side-on the slant thickness of the wall and earth cover would be greater, radiation effects would be reduced, and the number of deaths would still be the same as that due to blast alone.

95. Considering bombs burst above the ground more careful allowance must be made for the variation in slant thickness of the wall and its earth covering. For a trench with 1 foot of earth cover the portion of the wall (2 ft.) above the ground is considered in two parts and the slant thickness and hence the dose penetrating at points 6 and 18 inches above the ground level determined. Allowing as usual for the fraction of the shelter occupied by these doses, the risk rate due to the gamma radiation through the roof and side is calculated for the shelter as a whole, blast and gamma risks being combined to give the results shown in Table 20. The dose penetrating the wall at a point 6 inches below the ground level can also be determined but it is found that the gamma radiation only has any lethal risk at distances such that the blast risk rate at these distances is unity, and so the radiation has no effect on the total casualties.

TABLE 20

Comparison of deaths in side-on and end-on trenches
due to a low air burst bomb

Earth Cover (ft.)	Height of burst (yd.)	Blast Strength (lb/sq.ft.)	Total Deaths		
			Combined blast and gamma		Blast only
			Side-on	End-on	
1	220	1400	5680	5280	5130
		1000	7090	6940	6760

96. For the 500 and 250 lb/sq.ft. design blast pressures the deaths are independent of the shelter orientation and equal to the deaths due to blast alone.

97. These results show that for a 220 yd. height of burst the end-on position does not necessarily give the maximum number of deaths. However, the increase for the side-on position is small and is more than off-set by the diminution in deaths for a 440 or 660 yard height of burst when the weighted mean deaths are obtained by averaging over all heights of burst.

98. It can easily be deduced from the detailed calculations for 1 foot of earth cover that with 2 feet of earth cover the sideways-on position will give no increase in deaths over the end-on position for either a ground or low air burst bomb.

99. Thus for these partially sunk trenches the end-on position is the "worst-case" position for shelters of 1400 or 1000 lb/sq.ft. design blast pressure. For the weaker shelters the total weighted mean deaths are the same as for blast alone and so are independent of the orientation of the shelter.

VI. Safety-cost relationship

100. Using the figures for deaths given in Table 18, safety ratings, i.e. lives saved expressed as a percentage of the deaths (31,000) for a population all in houses, can be calculated for the various trench shelter designs, and are given in Table 21.

TABLE 21

Safety ratings for trench shelters

Design blast pressure (lb/sq.ft.)	Safety ratings for earth cover of:-			
	1 ft.	2 ft.	3 ft.	5 ft.
No blast deaths	84.1	93.9	98.3	99.9
1400	80.7	86.8	87.4	87.4
1000	75.8	81.0	81.6	81.6
500	56.1	56.8	56.8	-
250	1.6	-	-	-

101. The costs of the various trench shelters summarised in Table 22 are based on Grade A labour rates and prices of materials ruling at February, 1952 for construction on level sites in virgin ground and exclude the cost of any roads, paths and site works generally. The cost of electric wiring is included, but not the cost of bringing in the service mains. The cost of seating and internal fittings is not included. The costs are based on the assumption that open cut methods of excavation are not practicable; they would be increased where sites are restricted, where old foundations, rock, running sand, are encountered where sewers, gas, electric or water services have to be diverted, or where underpinning of adjacent buildings is necessary.

TABLE 22
Cost of Trench Shelters

Earth Cover (ft.)	Design blast pressure	Cost per head (£)	Weight of Steel per head (lb.)
1	1400	16.4	42.2
	1000	16.1	37.9
	500	15.8	34.0
	250	15.3	32.1
2	1400	17.8	47.3
	1000	17.4	47.0
	500	17.2	44.7
3	1400	19.1	51.9
	1000	18.9	50.5
	500	18.8	48.3
5	1400	22.2	62.3
	1000	22.0	60.5

102. These costs are plotted against the Safety Ratings in Fig. 12.

103. As in the corresponding section for surface shelters, safety ratings for each depth of earth cover are shown in Table 21 for the hypothetical case in which all the deaths are due to gamma radiation only (i.e. no blast deaths) and the safety rating-cost curves of Fig. 12 are extended - largely by guess - beyond the highest calculated point (1400 lb/sq.ft. pressure) so as to be asymptotic to this "all gamma" case.

104. In Fig. 12 the envelope curve shows that for 1 foot of earth cover the most efficient trench would be one designed for at least 1400 lb/sq.ft. but that for greater depths of earth cover the trenches should be designed to withstand greater blast pressures.

105. As explained in the Surface Shelter section (Part One, Section VIII) the point at which the tangent from the origin touches the envelope gives the optimum design of shelter below which it does not pay (in terms of cost per life saved) to go. For these trench shelters this optimum is between 1 and 2 ft. of earth cover and designed for at least 1400 lb/sq.ft.

VII. Effect of Softer Radiation

106. As shown in Table 18 nearly all the deaths in trench shelters are due to blast and it is only in the case of the mechanically stronger designs of trenches with 1 ft. of earth cover that there is any appreciable number of gamma deaths. Thus even if the radiation is less penetrating the only effect will be to increase somewhat the safety ratings for the trenches of 1400 and 1000 lb/sq.ft. blast pressure design and 1 foot of earth cover.

VIII. Conclusions

107. On the basis of the assumptions made in the preceding paragraphs the optimum trench shelter of those studied in this paper is the 1400 lb/sq.ft. design with about 18 ins. of earth cover. The 1400 lb/sq.ft. design has a concrete roof $7\frac{1}{2}$ ins. thick, so that the total cover for the optimum design is equivalent to about $19\frac{1}{2}$ ins. of concrete.

108. Should future tests show the radiation to be less penetrating than assumed, or should bombs larger than nominal be expected then the conclusion that it does not pay to use more than about 18 ins. of earth cover would be strengthened.

PART THREE

COMBINED ATOMIC AND H.E. SAFETY RATINGS

I. Introduction

109. In Parts One and Two of this study we have been concerned solely with safety against atomic attack. This was justified because all the shelters so far studied provided much the same safety against H.E. attack and such small variations as might exist would have little or no effect on the total safety of the shelters measured against a combined threat of which H.E. represented only a small part. Certain types of shelters (e.g. tunnels) with fairly thin overhead cover provide very much better protection against one form of attack than against the other and for these it is considered desirable to devise a combined H.E. and atomic safety rating which will allow better than standard protection from one form of attack to be offset against poor protection from the other.

110. The correct combination of the H.E. and atomic safety ratings demands a knowledge of the relative risks from these two forms of attack. Clearly this cannot be absolutely determined, but it has been stated (C.D.(0)(53)29) that the atomic bomb constitutes the most serious threat and that defence against it should be given the main consideration. This planning assumption will be arbitrarily interpreted to mean that the atomic risk at any rate in the opening phase of a war is 10 times the H.E. risk, i.e. the atomic attack is likely to cause at least 10 times as many casualties among a population in houses as the H.E. attack.

111. Total casualties from the attack may therefore be expressed as 10K atomic casualties and 1K H.E. casualties where K is a constant depending on the total weight of attack. Now if the atomic safety rating of a particular shelter is A, it is clear that it would save $\frac{10AK}{100}$ atomic casualties, and if its H.E. rating is H it would save $\frac{1HK}{100}$ H.E. casualties. The total saving is therefore $\frac{10AK + 1HK}{100}$

Converting this to a safety rating by dividing it by the casualties if there had been no shelter and multiplying by 100 we get:- combined safety rating: $\frac{10A + H}{11}$.

II. H.E. Safety Ratings

112. Appendix A of Ministry of Works Technical Memoranda "Air Raid Shelter" gives a formula from which the "area of vulnerability" of a person in any type of shelter may be calculated for H.E. Attack. This formula is

$$V = \frac{2000}{W} (0.8A + 1.6\ d\ A^{\frac{1}{2}} + 1.26\ d^2)$$

Where V is the area of vulnerability in sq.ft.
W is the weight in lb. of the H.E. bomb under consideration
A is the area of the shelter in sq.ft.
d is the near miss distance (in feet) within which shelter occupants are liable to be killed or injured.

For 500 lb. M.C. bombs d has the values of 12, 7 and 4 for 12 in., 18 in., and 24 in., R.C. walls respectively.

113. Applying this formula to the surface shelters considered in Part 1 gives values for the areas of vulnerability of 3,200 2,120 and 1,610 sq.ft. for the 12", 18" and 24" wall designs respectively.

114. Now last war experience* showed that the area of vulnerability of people in houses was about 5 times that of people in reinforced brick surface shelters. The latter should be equivalent to our present design of 12" R.C. surface shelter (V = 3,200 sq.ft.) and therefore on this basis the area of vulnerability of people in houses should be 16,000 sq.ft. This is in satisfactory agreement with the figure of 13,600 sq.ft. for killed plus seriously injured given in CDJPS(EA)(49)3. The area of vulnerability is, of course, directly proportional to the expected casualties from unit weight of attack, and the safety rating of the 12" R.C. shelter is therefore $\frac{16,000 - 3,200}{16,000} \times 100 = 80$. Corresponding figures for the 18" and 24" shelters are 87 and 90.

III. Combined Ratings for Surface Shelters

115. Table 23 gives the atomic safety ratings for surface shelters (from Table 9 Part One), the H.E. safety ratings, and the calculated combined safety rating (equals $\frac{10A + H}{11}$). For this Table it has been assumed that the H.E. ratings for the appropriate concrete thickness as calculated in para. 114 apply irrespective of the design strength of the shelter. In theory this cannot be true since an increase in strength must be accompanied by an increase in H.E. safety rating. However this increase is not likely to be large and last war data are insufficient to make any quantitative allowance for it.

TABLE 23

Combined Atomic and H.E. Safety Ratings
for Surface Shelters

Shielding Conditions	Design blast pressure (lb/sq.ft.)	Safety Rating								
		12" Shelter			18" Shelter			24" Shelter		
		Atomic	H.E.	Combined	Atomic	H.E.	Combined	Atomic	H.E.	Combined
Unshielded	1400	52.5	80	55.0	73.8	87	75.0	82.9	90	83.5
	1000	52.2	80	54.8	71.0	87	72.6	-	-	-
	500	42.1	80	45.7	-	-	-	-	-	-
Moderately Shielded	1400	65.4	80	66.7	81.9	87	82.3	86.0	90	86.4
	1000	64.4	80	65.8	78.0	87	78.9	-	-	-
	500	52.2	80	54.8	-	-	-	-	-	-
Well Shielded	1400	75.5	80	76.0	83.5	87	83.7	86.5	90	86.7
	1000	72.9	80	73.5	78.9	87	79.6	-	-	-
	500	54.5	80	56.9	-	-	-	-	-	-

*For example "Casualties from H.E. Bombs" CDJPS(EA)(49)3.

116. It will be seen from Table 23 that in no case is the combined rating very different from the atomic rating, and an examination of Fig. 6 shows that none of the conclusions drawn from that figure would be affected if it were drawn (as if should be) in terms of combined ratings instead of only atomic ratings.

PART FOUR

(This part of the paper has been prepared in the Scientific Advisers' Branch Home Office and has not been considered by Ministry of Works.)

EFFECTS OF VARIATIONS IN RISK OF ATTACK

117. The conclusions so far reached about optimum shelter standards strictly speaking only relate to an area or areas where the likelihood of attack is uniform. Where this is not the case then the safety ratings must be multiplied by the relative likelihood of attack to make them proportional to the lives saved, since it is the lives saved which are the true measure of the "safety" of any scheme. For example consider two areas of equal size and equal population density (43.6 per acre) one of which is expected to receive two bombs and the other a single bomb. Suppose that moderately shielded 15"/1400 lb/sq.ft. shelters were built in each (safety rating 75.2). Then in the single bomb area we should save .752 x 31,000 = 23,200 lives and in the two bomb area 2 x .752 x 31,000 = 46,400 lives (assuming that the areas were big enough to absorb the effects of the bombs without overlap). But the total cost of shelters in the two areas would be the same (since their populations are the same) and therefore the cost per life saved in the two bomb area would be half that in the one bomb area. Applying this argument to the safety rating - cost curves of Fig. 6 leads to the following conclusions:-

(i) The "optimum" standards are not affected - it never pays to build shelters to a lower standard than this irrespective of the likelihood of attack.

(ii) If one area is appreciably more likely to be attacked than another, then shelter in the more risky area, should be built to a higher standard than the "optimum" even if this means leaving some of the people in the less risky area without shelter. For example it can be deduced from Fig. 6 that for moderately shielded surface shelters in areas where the risk rates are in the ratio of 2 to 1, everyone in the higher risk area should be given a shelter costing about £19 per head (safety rating 83) before anyone in the lower risk area is given an 'optimum' shelter (cost £16.7, safety rating 75.2)

118. In addition to the variations in risk from area to area discussed above, there will also be variations in risk within a single area which may invalidate the conclusions so far reached regarding the optimum shelter. It cannot be too strongly emphasised that these conclusions are only valid for an area or areas where the risk is uniform. If, in any particular area, a bomb is more likely to fall in one place, than in another, then the provision of optimum shelters throughout the area will not result in the greatest saving in life for the money spent. This point can perhaps be illustrated by considering the case of a fairly small, compact town (population of the order of 50-100 thousand). In such a town the aiming point is fairly certain to be at, or very close to, the centre and therefore irrespective of the accuracy of attack actually achieved by the enemy, the risk at the centre of the town must always be greater than in the suburbs. The numerical variation in risk, and hence in the standard of protection which should be provided, from place to place in the town depends, of course, on the enemy's aiming accuracy. In the limit, however, if it were known that he could burst his bomb at ground level exactly on the centre of the town, then the minimum efficient (or optimum) shelter at each distance from the centre of the town would be that which gave protection at that distance, i.e. we should have to provide "bomb proof" shelter at the centre and no shelter at all beyond about a mile from the centre since people in houses should be fairly safe at that distance. This, of course, is a reductio ad absurdum argument, since aiming points will seldom be precisely determinable, and since attacks will never achieve pin-point accuracy. In practice it might be possible, using some such method as that recommended by

the U.S. authorities* to define likely aiming points and to assign a probable aiming error to the attack. In this way the relative risk in different zones in a single area could be estimated, and hence the optimum standard of shelter for each zone could be determined.

119. If the variation in risk discussed above, that is from area to area and from zone to zone within a single area, were taken into account in determining the optimum shelter design for each area and zone, then the result would be a number of optimum designs for each type of shelter, each applicable to a particular degree of risk. It is quite certain that such a differentiated policy would save more lives for a given expenditure than would the application of a single standard to all areas where shelter was provided. A substantial amount of work would, however, have to be undertaken to determine the magnitude of this extra saving in life, and it is at present impossible to forecast whether the saving would be sufficient to compensate for the political and morale objections to a differentiated shelter policy.

PART FIVE

RECOMMENDATIONS FOR FUTURE STUDIES

I. Shelter provision relative to risk

120. The conclusions reached in this study are based on the assumption of equal risk in all areas where shelter is provided, and on this basis a single 'optimum' standard for each type of shelter is recommended. It is possible that a greater saving in life for a given expenditure could be achieved by recognising that the risk is not in fact uniform in all shelter areas, by dividing these areas up into a number of 'risk' categories, and by determining the optimum standard corresponding to each degree of risk. The point is, of course, that it may not be worth while (in terms of cost per life saved) to build optimum shelters in the lower risk areas until something better than optimum has been provided in the higher risk areas.

121. This approach, of trying to relate the standard of protection in any area to the degree of risk in that area, has not been followed up in the present paper. It may, however, lead to a shelter policy which leaves many people in the 'shelter areas' without shelter unless the overall cost of the programme is increased.

122. The objections from a morale point of view of reducing the number of people for whom shelter is provided in order to pay for better shelters for those in the higher risk areas have to be weighed against the extra saving in life that would result from this policy. A considerable amount of work would have to be done before any estimate could be made of the likely magnitude of this extra saving. This work would have to be put in hand if the best theoretical solution of the shelter problem were desired, but if the practical objections to having shelter of varying standards in different areas are so strong that such a policy could not be adopted, than the work would be of only theoretical interest, and other shelter studies should be given priority.

II. Design considerations

123. The methods used for designing the shelters in the present series against blast - designing them against a uniformly distributed static load on the roof and sides of one seventh of the estimated peak blast pressure - cannot be considered satisfactory or final. The analysis of the results of past atomic trials and other tests, and the planning of future tests to yield the required data are being pursued in an attempt to devise a more satisfactory design procedure. Design against gamma radiation, although probably resting on a rather sounder theoretical basis than design against blast, cannot be considered final. In particular the analysis of those aspects of the recent atomic trials in Australia which bear on this aspect should be given priority.

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*United States Federal Civil Defence Adminstration Report No. TM-8-1 "Civil Defence Urban Analysis".

124. The most important type of shelter omitted from the present studies is perhaps the Anderson shelter, and an extension of the safety rating - cost analysis to the Anderson shelter should be undertaken.

125. The Anderson shelter was designed long before the atomic bomb was invented, and even before any real experience of the effects of H.E. bombs was available. It would be surprising, therefore, if the present design represented the most efficient (on a safety-cost basis) possible design of back garden shelter. It is for consideration, therefore, whether, in the light of present knowledge of the effects of atomic bombs and with possible help from future trials, an attempt should be made to design a more efficient back-garden shelter.

126. A number of extensions to the present studies have been suggested in this report, and these should be undertaken. The most important of these are the possibility of designing aurface shelters to carry a load of 1400 lb/sq.ft. with roofs thinner than 12 ins. the balance of the roof protection being made up with earth, and an extension of the surface and trench shelter studies to design loads greater than 1400 lb/sq.ft.

III. Costs and resources studies

127. The present studies have been confined to a single size and lay-out of surface and trench shelter. For a given strength and thickness it can probably be assumed that atomic safety is independent of size and shape, but the costs of other sizes and shapes should be determined.

128. Basements in buildings appear to offer possibilities of providing reasonable shelter at comparatively small cost, and the safety/cost relationship for a number of basements in both framed and unframed buildings, improved and strengthened to various degrees, should be investigated.

129. If safety and cost (in terms of £.s.d.) were the only criteria of a shelter programme, then extensions of the present studies on the lines outlined above should provide all the information necessary to devise an efficient shelter policy. However in an emergency of the type envisaged, a substantial proportion of the resources of the country will be available to build as many shelters as possible in a limited warning period. The true criterion will not be cost in terms of £.s.d, but cost in terms of labour and materials. The best method of shelter provision will be that which produces the greatest number of good shelters out of the available pool of labour and materials. An estimate must therefore be made of the probable size of that pool in the likely warning period, and any proposed shelter programme must be measured against it. It is possible that a programme based on the present studies would make excessive demands on certain materials (e.g. steel and cement) and on certain skills (e.g. the various trades associated with building in-situ reinforced concrete.)

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APPENDIX

TABLE 1

Distance-risk rates for gamma radiation

Shelter Side-on: Unshielded

Thickness of roof and walls	Distance from G.Z. (yards)	¾ mile burst			½ mile burst			¼ mile burst			Ground level burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.89	.89	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.81	.81	.28	.72	1.0	.56	.44	1.0	1.0	0	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0	1.0	0	1.0
	450	0	.66	.66	.51	.49	1.0	.76	.24	1.0	1.0	0	1.0
	550	.04	.34	.38	.60	.40	1.0	.80	0	.80	1.0	0	1.0
	650	0	.02	.02	.66	.03	.69	.83	0	.83	1.0	0	1.0
	750				.62	0	.62	.85	0	.85	1.0	0	1.0
	850				.28	0	.28	.88	0	.88	1.0	0	1.0
	950							.41	0	.41	0.72	0	.72
	1050							.02	0	.02	.14	0	.14
15 inches	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.89	.89	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.81	.81	.11	.72	.83	.56	.44	1.0	1.0	0	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0	1.0	0	1.0
	450	0	.32	.32	.51	.49	1.0	.76	0	.76	1.0	0	1.0
	550				.60	.05	.65	.80	0	.80	1.0	0	1.0
	650				.42	0	.42	.83	0	.83	1.0	0	1.0
	750				.16	0	.16	.85	0	.85	1.0	0	1.0
	850							.39	0	.39	.83	0	.83
	950										.20	0	.20
18 inches	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.89	.89	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.81	.81	0	.72	.72	.56	.44	1.0	1.0	0	1.0
	350	0	.31	.31	.10	.60	.70	.69	.19	.88	1.0	0	1.0
	450				.20	.14	.34	.76	0	.76	1.0	0	1.0
	550				.17	0	.17	.80	0	.80	1.0	0	1.0
	650				.03	0	.03	.83	0	.83	1.0	0	1.0
	750							.46	0	.46	.88	0	.88
	850							.02	0	.02	.22	0	.22
24 inches	50	0	.34	.34	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.20	.20	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250				0	.66	.66	.56	.44	1.0	1.0	0	1.0
	350				0	.03	.03	.69	0	.69	1.0	0	1.0
	450							.76	0	.76	1.0	0	1.0
	550							.46	0	.46	1.0	0	1.0
	650							.07	0	.07	.45	0	.45

APPENDIX

TABLE 2

Distance-risk rates for gamma radiation
Shelter side-on; shielded by a building
20 ft. high at a distance of 30 ft.

Thickness of roof and walls	Distance from G.Z. (yards)	$\frac{3}{8}$ mile burst			$\frac{1}{4}$ mile burst			$\frac{1}{8}$ mile burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	.28	.72	1.0	.56	.44	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0
	450	0	.66	.66	.51	.49	1.0	.76	.24	1.0
	550	.04	.34	.38	.60	.40	1.0	.78	0	.78
	650	0	.02	.02	.66	.03	.69	.25	0	.25
	750				.53	0	.53			
	850				.14	0	.14			
15 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	.11	.72	.83	.56	.44	1.0
	350	0	.73	.73	.40	.60	1.0	.69	.31	1.0
	450	0	.32	.32	.51	.49	1.0	.76	0	.76
	550				.60	.05	.65	.25	0	.25
	650				.42	0	.42			
	750				.13	0	.13			
18 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	0	.72	.72	.56	.44	1.0
	350	0	.31	.31	.10	.60	.70	.69	.19	.88
	450				.20	.14	.34	.45	0	.45
	550				.17	0	.17			
	650				.03	0	.03			
24 inches	50	0	.34	.34	0	.94	.94	0	.89	.89
	150	0	.20	.20	0	.83	.83	.34	.66	1.0
	250				0	.66	.66	.56	.44	1.0
	350				0	.03	.03	.68	0	.68
	450							.25	0	.25

TABLE 3

Distance-risk rates for gamma radiation
Shelter side-on; shielded by a building 50 ft.
high, at a distance of 20 ft.

Thickness of roof and walls	Distance from G.Z. (yards)	$\frac{3}{8}$ mile burst			$\frac{1}{4}$ mile burst			$\frac{1}{8}$ mile burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	0	.72	.72	.56	.44	1.0
	350	0	.30	.30	0	.42	.42	.15	0	.15
15 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.34	.66	1.0
	250	0	.81	.81	0	.61	.61	.29	.44	.73
	350	0	.30	.30	0	.03	.03			
18 inches	50	0	.96	.96	0	.94	.94	0	.89	.89
	150	0	.89	.89	0	.83	.83	.15	.66	.81
	250	0	.81	.81	0	.27	.27	.26	.32	.58
	350	0	.13	.13						
24 inches	50	0	.34	.34	0	.94	.94	0	.89	.89
	150	0	.20	.20	0	.83	.83	0	.66	.66
	250				0	.11	.11			

APPENDIX

TABLE 4

Distance-risk rates for gamma radiation

Shelter End-on; Unshielded

Thickness of roof and walls	Distance from G.Z. (yards)	$\frac{3}{8}$ mile burst			$\frac{1}{4}$ mile burst			$\frac{1}{8}$ mile burst			Ground level burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
12 inches	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.977	.977	0	.966	.966	.068	.932	1.0	1.0	0	1.0
	250	0	.962	.962	.016	.943	.959	.114	.886	1.0	1.0	0	1.0
	350	0	.947	.947	.023	.920	.943	.159	.841	1.0	1.0	0	1.0
	450	.001	.932	.933	.029	.898	.927	.204	.796	1.0	1.0	0	1.0
	550	.002	.550	.552	.036	.875	.911	.175	0	.175	1.0	0	1.0
	650	0	.054	.054	.043	.077	.120	.095	0	.095	.63	0	.63
	750				.043	0	.043	.098	0	.098	.286	0	.286
	850				.020	0	.020	.110	0	.110	.286	0	.286
	950							.057	0	.057	.206	0	.206
	1050							.003	0	.003	.043	0	.043
15 inches	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.977	.977	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250	0	.962	.962	.006	.943	.949	.065	.886	.951	1.0	0	1.0
	350	0	.947	.947	.023	.920	.943	.084	.841	.925	1.0	0	1.0
	450	0	.456	.456	.029	.898	.927	.068	0	.068	1.0	0	1.0
	550				.036	.105	.141	.071	0	.071	.42	0	.42
	650				.027	0	.027	.085	0	.085	.286	0	.286
	750				.011	0	.011	.098	0	.098	.286	0	.286
	850							.049	0	.049	.229	0	.229
	950										.057	0	.057
18 inches	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.977	.977	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250	0	.962	.962	0	.943	.943	.033	.886	.919	1.0	0	1.0
	350	0	.407	.407	.006	.920	.926	.045	.522	.567	.950	0	.950
	450				.011	.26	.271	.059	.0	.059	.286	0	.286
	550				.010	0	.010	.071	0	.071	.286	0	.286
	650				.002	0	.002	.085	0	.085	.286	0	.286
	750							.052	0	.052	.252	0	.252
	850							.002	0	.002	.069	0	.069
24 inches	50	0	.337	.337	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.195	.195	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250				0	.866	.866	.033	.886	.919	.286	0	.286
	350				0	.046	.046	.045	0	.045	.286	0	.286
	450							.059	0	.059	.286	0	.286
	550							.045	0	.045	.286	0	.286
	650							.004	0	.004	.129	0	.129

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APPENDIX

TABLE 5

DEATHS IN SURFACE SHELTERS

UNSHIELDED

Design blast pressure (lb/sq.ft.)	Orientation	Ht. of burst	12" Shelter Deaths	15" Shelter Deaths	18" Shelter Deaths	24" Shelter Deaths
1400	Side-on	0	27,560	23,140	18,520	11,840
		1/8	22,510	19,410	14,550	8,260
		1/4	16,690	11,270	6,030	4,100
		3/8	6,540	4,430	2,780	270
	Weighted mean		18,840	14,870	10,400	6,140
	End-on	0	16,500	12,050	9,010	7,600
		1/8	9,210	6,560	6,050	5,380
		1/4	10,430	7,440	5,440	4,100
		3/8	8,610	5,500	3,280	260
	Weighted mean		10,640	7,530	5,860	4,410
	Mean of end-on and side-on		14,740	11,200	8,130	5,270
1000	Side-on	0	27,560	23,140	18,520	
		1/8	22,650	19,410	14,790	
		1/4	16,690	11,390	7,370	
		3/8	6,660	4,520	2,920	
	Weighted mean		18,900	14,930	10,970	
	End-on	0	16,500	12,150	10,270	
		1/8	9,520	8,010	7,550	
		1/4	10,590	7,910	6,760	
		3/8	8,620	5,510	3,340	
	Weighted mean		10,800	8,220	7,050	
	Mean of end-on and side-on		14,850	11,570	9,010	
500	Side-on	0	27,560	23,140		
		1/8	23,310	19,500		
		1/4	18,210	15,340		
		3/8	14,810	14,300		
	Weighted mean		20,890	17,810		
	End-on	0	16,860	14,560		
		1/8	14,210	13,640		
		1/4	14,820	14,510		
		3/8	15,110	14,390		
	Weighted mean		14,950	14,190		
	Mean of end-on and side-on		17,920	16,000		
No blast deaths	Side-on	0	27,560	23,140	18,640	11,840
		1/8	22,730	17,450	13,780	7,500
		1/4	16,530	10,910	4,870	1,960
		3/8	6,550	4,430	2,780	270
	Weighted mean		18,860	14,060	9,740	5,130
	End-on	0	16,500	12,050	6,490	4,200
		1/8	9,210	5,640	4,420	2,760
		1/4	10,230	7,240	4,990	2,410
		3/8	8,610	5,500	3,280	260
	Weighted mean		10,580	7,140	5,060	2,490
	Mean of end-on and side-on		14,720	10,600	7,400	3,810

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APPENDIX

TABLE 6

DEATHS IN SURFACE SHELTERS

MODERATELY SHIELDED (SHIELDING ANGLE $17^{\circ} - 51^{\circ}$)

Design blast pressure (lb/sq.ft.)	12" Shelter			15" Shelter			18" Shelter			24" Shelter		
	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths	Orientation	Ht. of burst	Deaths
1400	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060
		1/8	10,420		1/8	7,410		1/8	6,080		1/8	5,710
		1/4	15,640		1/4	11,160		1/4	6,030		1/4	4,100
		3/8	6,540		3/8	4,430		3/8	2,780		3/8	270
	Weighted mean		10,870	Weighted mean		7,930	Weighted mean		5,440	Weighted mean		4,250
	End-on	0	16,500	End-on	0	12,050	End-on	0	9,010	End-on	0	7,000
		1/8	9,210		1/8	6,560		1/8	6,050		1/8	5,380
		1/4	10,430		1/4	7,440		1/4	5,440		1/4	4,100
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,640	Weighted mean		7,530	Weighted mean		5,860	Weighted mean		4,410
	Mean of end-on and side-on		10,750	Mean of end-on and side-on		7,730	Mean of end-on and side-on		5,650	Mean of end-on and side-on		4,330
1000	Side-on	0	6,860	Side-on	0	6,860	Side-on	0	6,860			
		1/8	10,510		1/8	7,980		1/8	7,090			
		1/4	15,640		1/4	11,340		1/4	7,370			
		3/8	6,620		3/8	4,520		3/8	2,920			
	Weighted mean		11,180	Weighted mean		8,480	Weighted mean		6,540			
	End-on	0	16,500	End-on	0	12,150	End-on	0	10,270			
		1/8	9,520		1/8	8,010		1/8	7,550			
		1/4	10,590		1/4	7,910		1/4	6,760			
		3/8	8,620		3/8	5,510		3/8	3,340			
	Weighted mean		10,800	Weighted mean		8,220	Weighted mean		7,050			
	Mean of end-on and side-on		10,990	Mean of end-on and side-on		8,350	Mean of end-on and side-on		6,800			
500	Side-on	0	11,270	S'de-on	0	11,270						
		1/8	13,360		1/8	13,100						
		1/4	1[illegible],370		1/4	15,330						
		3/8	14,810		3/8	14,300						
	Weighted mean		14,670	Weighted mean		13,780						
	End-on	0	16,860	End-on	0	14,560						
		1/8	14,210		1/8	13,640						
		1/4	14,820		1/4	14,510						
		3/8	15,110		3/8	14,390						
	Weighted mean		14,950	Weighted mean		14,190						
	Mean of end-on and side-on		14,810	Mean of end-on and side-on		13,990						
No blast deaths	Side-on	0	0	Side-on	0	0	Side-on	0	0	Side-on	0	0
		1/8	10,390		1/8	7,210		1/8	5,400		1/8	4,500
		1/4	15,470		1/4	10,790		1/4	4,870		1/4	1,960
		3/8	6,550		3/8	4,430		3/8	2,780		3/8	270
	Weighted mean		10,040	Weighted mean		6,960	Weighted mean		4,010	Weighted mean		2,300
	End-on	0	16,500	End-on	0	12,050	End-on	0	8,490	End-on	0	4,200
		1/8	9,210		1/8	5,640		1/8	4,420		1/8	2,760
		1/4	10,230		1/4	7,240		1/4	4,990		1/4	2,410
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,580	Weighted mean		7,140	Weighted mean		5,060	Weighted mean		2,490
	Mean of end-on and side-on		10,310	Mean of end-on and side-on		7,050	Mean of end-on and side-on		4,540	Mean of end-on and side-on		2,400

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APPENDIX

TABLE 7

DEATHS IN SURFACE SHELTERS

WELL SHIELDED (SHIELDING ANGLE 51°)

Design blast pressure (lb/sq.in.)	12" Shelter Orientation	12" Ht. of burst	12" Deaths	15" Shelter Orientation	15" Ht. of burst	15" Deaths	18" Shelter Orientation	18" Ht. of burst	18" Deaths	24" Shelter Orientation	24" Ht. of burst	24" Deaths
1400	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060	Side-on	0	5,060
		1/8	5,130		1/8	5,110		1/8	5,110		1/8	5,110
		1/4	4,400		1/4	4,080		1/4	4,020		1/4	4,000
		3/8	2,760		3/8	2,760		3/8	2,330		3/8	270
	Weighted mean		4,510	Weighted mean		4,390	Weighted mean		4,310	Weighted mean		3,990
	End-on	0	16,500	End-on	0	12,050	End-on	0	9,010	End-on	0	7,000
		1/8	9,210		1/8	6,560		1/8	6,050		1/8	5,320
		1/4	10,430		1/4	7,440		1/4	5,440		1/4	4,100
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,640	Weighted mean		7,530	Weighted mean		5,860	Weighted mean		4,410
	Mean of end-on and side-on		7,570	Mean of end-on and side-on		5,960	Mean of end-on and side-on		5,080	Mean of end-on and side-on		4,200
1000	Side-on	0	6,860	Side-on	0	6,860	Side-on	0	6,860			
		1/8	6,780		1/8	6,780		1/8	6,780			
		1/4	6,450		1/4	6,450		1/4	6,450			
		3/8	2,900		3/8	2,900		3/8	2,570			
	Weighted mean		6,100	Weighted mean		6,100	Weighted mean		6,050			
	End-on	0	16,500	End-on	0	12,150	End-on	0	10,270			
		1/8	9,520		1/8	8,010		1/8	7,550			
		1/4	10,590		1/4	7,910		1/4	6,760			
		3/8	8,620		3/8	5,510		3/8	3,340			
	Weighted mean		10,800	Weighted mean		8,220	Weighted mean		7,050			
	Mean of end-on and side-on		8,450	Mean of end-on and side-on		7,160	Mean of end-on and side-on		6,550			
500	Side-on	0	11,270	Side-on	0	11,270						
		1/8	12,890		1/8	12,890						
		1/4	14,440		1/4	14,440						
		3/8	14,130		3/8	14,130						
	Weighted mean		13,350	Weighted mean		13,380						
	End-on	0	16,860	End-on	0	14,560						
		1/8	14,210		1/8	13,640						
		1/4	14,820		1/4	14,510						
		3/8	15,110		3/8	14,390						
	Weighted mean		14,950	Weighted mean		14,190						
	Mean of end-on and side-on		14,150	Mean of end-on and side-on		13,780						
No 'last deaths	Side-on	0	0	Side-on	0	0	Side-on	0	0	Side-on	0	0
		1/8	2,810		1/8	2,130		1/8	1,760		1/8	810
		1/4	2,820		1/4	1,890		1/4	1,350		1/4	1,130
		3/8	2,760		3/8	2,760		3/8	2,430		3/8	270
	Weighted mean		2,380	Weighted mean		1,820	Weighted mean		1,450	Weighted mean		720
	End-on	0	16,500	End-on	0	12,050	End-on	0	8,490	End-on	0	4,200
		1/8	9,210		1/8	5,640		1/8	4,420		1/8	2,760
		1/4	10,230		1/4	7,240		1/4	4,990		1/4	2,410
		3/8	8,610		3/8	5,500		3/8	3,280		3/8	260
	Weighted mean		10,580	Weighted mean		7,140	Weighted mean		5,060	Weighted mean		2,490
	Mean of end-on and side-on		6,480	Mean of end-on and side-on		4,480	Mean of end-on and side-on		3,250	Mean of end-on and side-on		1,600

CONFIDENTIAL

(19908)

APPENDIX

TABLE 8

Distance-risk rates for 1 MeV gamma radiation

Walls and roof of shelter 12 inches thick

Shelter position	Distance from G.Z. (yards)	¾ mile burst			½ mile burst			¼ mile burst			Ground level burst		
		Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total	Wall	Roof	Total
Side-on unshielded	50	0	.96	.96	0	.94	.94	0	.89	.89	1.0	0	1.0
	150	0	.71	.71	0	.83	.83	.34	.66	1.0	1.0	0	1.0
	250	0	.31	.31	0	.72	.72	.56	.44	1.0	1.0	0	1.0
	350				0	.27	.27	.69	0	.69	1.0	0	1.0
	450							.76	0	.76	1.0	0	1.0
	550							.80	0	.80	1.0	0	1.0
	650							.45	0	.45	1.0	0	1.0
	750							.04	0	.04	.36	0	.36
Side-on moderately shielded	50	0	.96	.96	0	.94	.94	0	.89	.89			
	150	0	.71	.71	0	.83	.83	.34	.66	1.0			
	250	0	.31	.31	0	.72	.72	.56	.44	1.0			
	350				0	.27	.27	.66	0	.66			
	450							.25	0	.25			
End-on unshielded	50	0	.992	.992	0	.989	.989	0	.977	.977	1.0	0	1.0
	150	0	.859	.859	0	.966	.966	.019	.932	.951	1.0	0	1.0
	250	0	.360	.366	0	.943	.943	.033	.886	.919	.493	0	.493
	350				0	.414	.414	.045	0	.045	.286	0	.286
	450							.059	0	.059	.286	0	.286
	550							.071	0	.071	.286	0	.286
	650							.046	0	.046	.286	0	.286
	750							.005	0	.005	.103	0	.103

APPENDIX

TABLE 9

Deaths due to blast and 1 MeV radiation in 12" surface shelters

Design Blast Pressure (lb/sq.ft.)	Orientation	Height of Burst (mile)	Unshielded	Moderately shielded	Subjected to blast only
1400	Side-on	0	13,850	5,190	5,190
		1/8	10,510	5,220	5,130
		1/4	4,300	4,300	3,990
		3/8	1,310	1,310	0
	Weighted mean		7,600	4,310	3,970
	End-on	0	8,100	8,100	As above
		1/8	5,650	5,650	
		1/4	4,440	4,440	
		3/8	1,560	1,560	
	Weighted mean		4,980	4,980	3,970
	Mean of side-on and end-on		6,290	4,640	3,970
1000	Side-on	0	13,850	6,950	6,950
		1/8	11,290	6,760	6,760
		1/4	6,410	6,410	6,400
		3/8	1,610	1,610	620
	Weighted mean		8,510	5,890	5,740
	End-on	0	9,370	9,370	As above
		1/8	7,190	7,190	
		1/4	6,420	6,420	
		3/8	1,790	1,790	
	Weighted mean		6,440	6,440	5,740
	Mean of side-on and end-on		7,480	6,160	5,740
500	Side-on	0	15,420	11,270	11,270
		1/8	13,910	13,060	13,060
		1/4	14,470	14,470	14,470
		3/8	14,090	14,090	14,090
	Weighted mean		14,350	13,440	13,440
	End-on	0	12,460	12,460	As above
		1/8	13,150	13,150	
		1/4	14,470	14,470	
		3/8	14,090	14,090	
	Weighted mean		13,650	13,650	13,440
	Mean of side-on and end-on		14,000	13,540	13,440
No blast deaths	Side-on	0	15,380	0	0
		1/8	10,120	4,460	0
		1/4	2,520	2,520	0
		3/8	1,310	1,310	0
	Weighted mean		6,930	2,640	0
	End-on	0	5,510	As unshielded	0
		1/8	2,760		0
		1/4	3,250		0
		3/8	1,530		0
	Weighted mean		3,160	3,160	0
	Mean of side-on and end-on		5,040	2,900	0

APPENDIX

TABLE 10

Distance-risk rates for gamma radiation
Trench shelters; end-on unshielded

Earth Cover (ft.)	Roof Thickness (in.)	Distance from G.Z. (yd.)	Gamma risk rate (roof)*		
			$\frac{3}{8}$ mile burst	$\frac{1}{4}$ mile burst	$\frac{1}{8}$ mile burst
1	7.5	0-250	1.0	1.0	1.0
		350	1.0	1.0	
		450	.40	1.0	
		550		.03	
	6	0-350	1.0	1.0	1.0
		450	.75	1.0	.24
		550	.17	.38	
	5	0-350	1.0	1.0	1.0
		450	1.0	1.0	.64
		550	.36	.69	
2	7.5	50	.44	1.0	1.0
		150	.28	1.0	1.0
		250		1.0	1.0
		350		.10	
	6	50	.75	1.0	1.0
		150	.55	1.0	1.0
		250	.22	1.0	1.0
		350		.38	
	5	50	1.0	1.0	1.0
		150	.80	1.0	1.0
		250	.41	1.0	1.0
		350		.62	
3	7.5	50	0	.75	1.0
		150		.26	1.0
	6	50	0	1.0	1.0
		150		.53	1.0
		250			.09
5	7.5	50	0	0	.15
	6.5	50	0	0	.26

*Shelters assumed to be infinitely long and so all the radiation is received through the roof.

APPENDIX

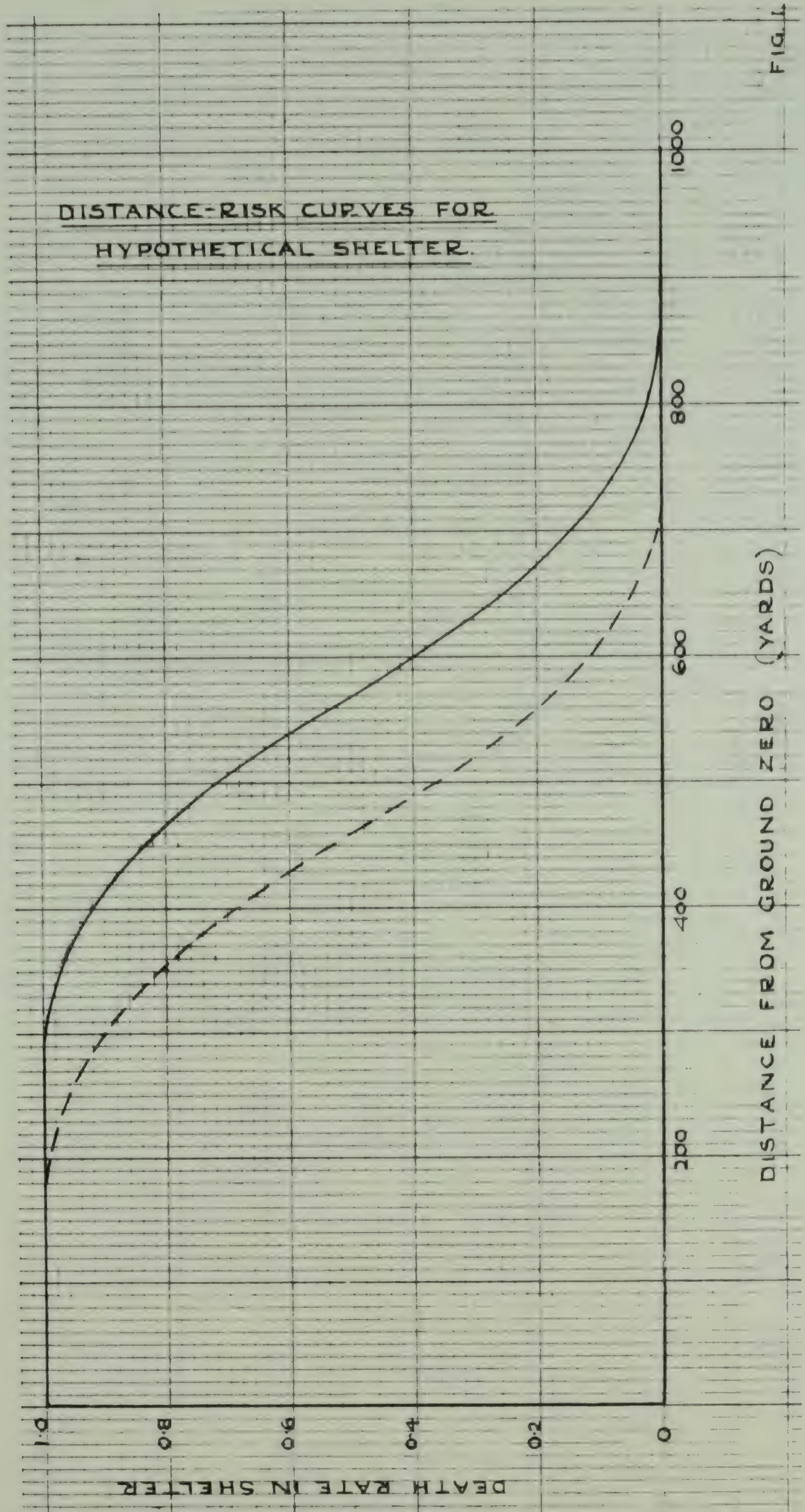
TABLE 11

Deaths in trench shelters; end-on; unshielded

Design blast pressure (lb/sq.ft.)	Height of Burst (mile)	Deaths for earth cover of depth:- 1 ft.	2 ft.	3 ft.	5 ft.
1400	0+	5190	5190	5190	5190
	1/8	5280	5130	5130	5130
	1/4	7160	4200	3990	3990
	3/8	5540	360	0	0
Weighted mean		5970	4100	3970*	3970*
1000	0+	6950	6950	6950	6950
	1/8	6940	6760	6760	6760
	1/4	8500	6400	6400	6400
	3/8	6960	1380	620	620
Weighted mean		7490	5860	5740*	5740*
500	0+	11270	11270	11270	
	1/8	13060	13060	13060	
	1/4	14500	14470	14470	
	3/8	15020	14090	14090	
Weighted mean		13590	13440*	13440*	
250	0+	23100			
	1/8	28180			
	1/4	31910			
	3/8	40360			
Weighted mean		30540*			
No blast deaths	0	0	0	0	0
	1/8	4520	2540	1130	10
	1/4	7160	2740	430	0
	3/8	5540	360	0	0
Weighted mean		4920	1900	550	0

+Assumed that for a ground burst there are no deaths due to gamma radiation

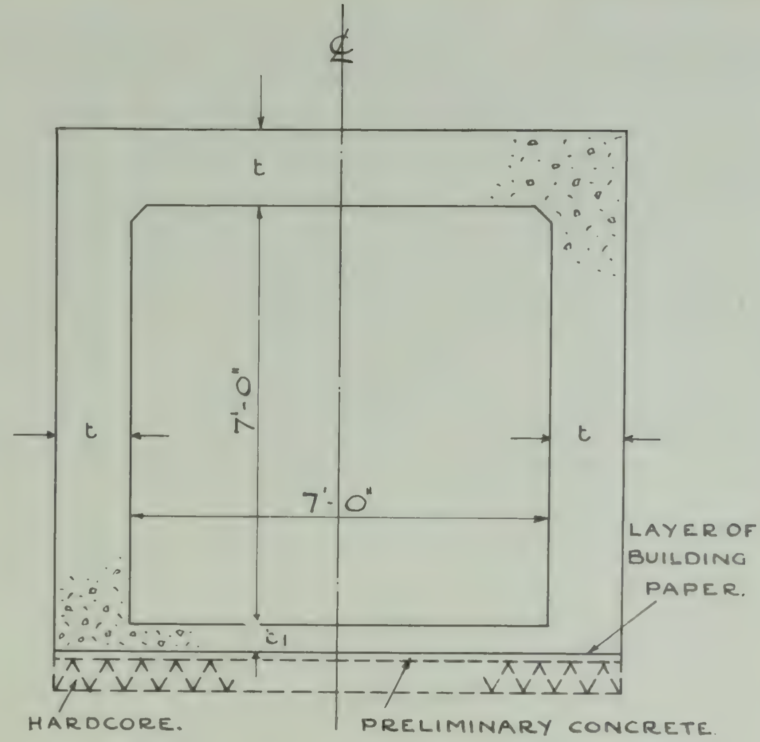
*No. of deaths the same as for blast alone.



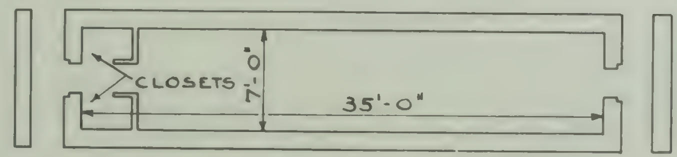
DISTANCE-RISK CURVES FOR
HYPOTHETICAL SHELTER.
DEATH RATE IN SHELTER
1·0
0·8
0·6
0·4
0·2
0
DISTANCE FROM GROUND ZERO (YARDS)
200
400
600
800
1000

FIG. I.

CASE NO.	BLAST LOAD	ROOF & WALL THICK-NESS t (IN)	FLOOR THICK-NESS t_1 (IN)	WT. OF REINFORCEMENT PER FT. RUN OF SHELTER (LB)	TOTAL WT. OF STEEL IN SHELTER (LB)
1	1400	12	5	46·2	2249
	1000	"	"	37·4	1840
	500	"	"	22·5	1155
	250	"	"	"	"
2	1400	15	5	44·3	2218
	1000	"	"	30·7	1578
	500	"	"	27·3	1427
	250	"	"	"	"
3	1400	18	5	41·7	2170
	1000	"	"	32·4	1747
	500	"	"	"	"
	250	"	"	"	"
4	1400	24	5	43·9	2411
	1000	"	"	"	"
	500	"	"	"	"
	250	"	"	"	"



CROSS SECTION.



PLAN

SURFACE SHELTERS.

FIG. 2.

(19908)

SURFACE SHELTERS.

DISTANCE-RISK CURVES FOR BLAST

1400 lb / SQ. FT. DESIGN.

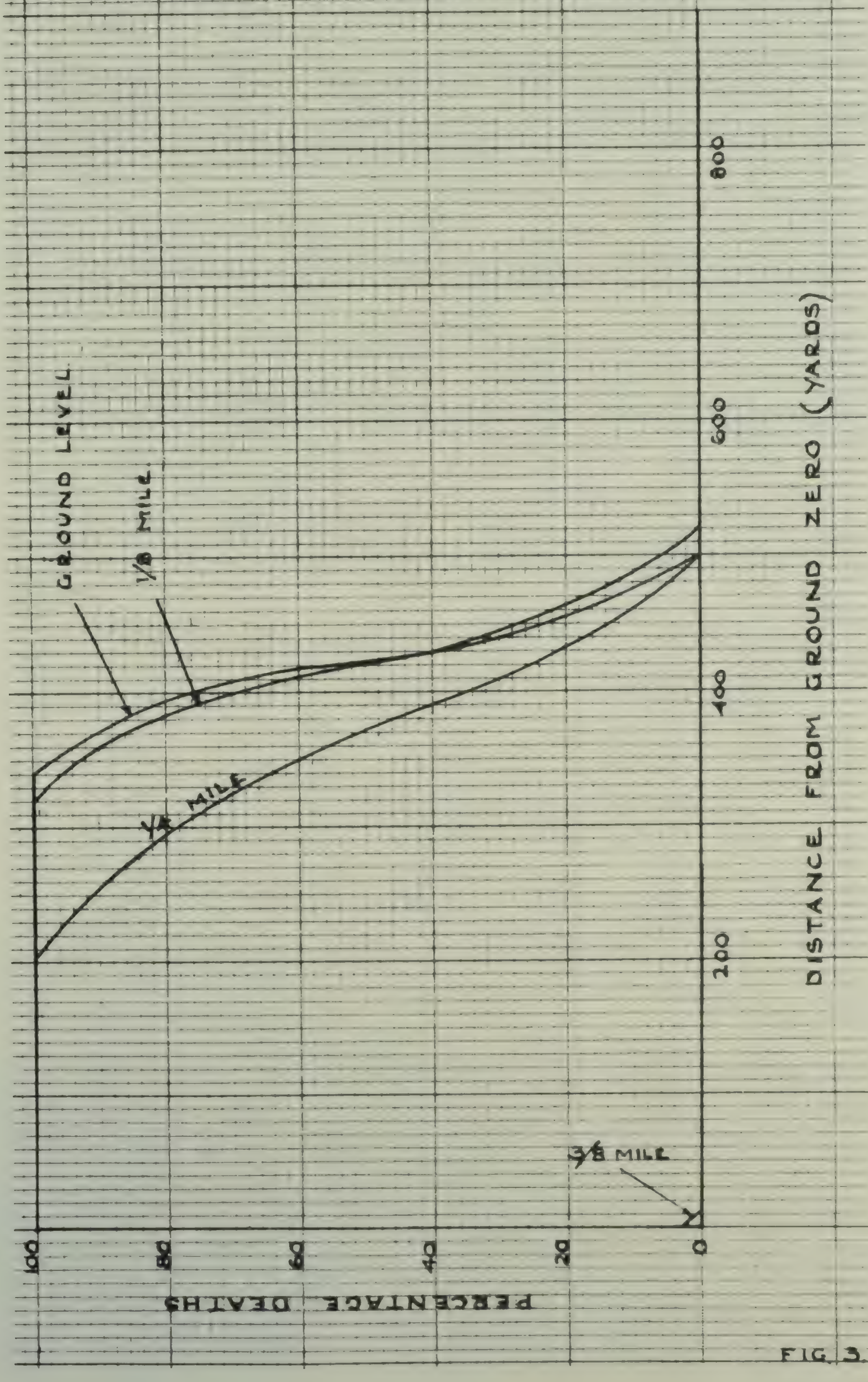


FIG. 3.

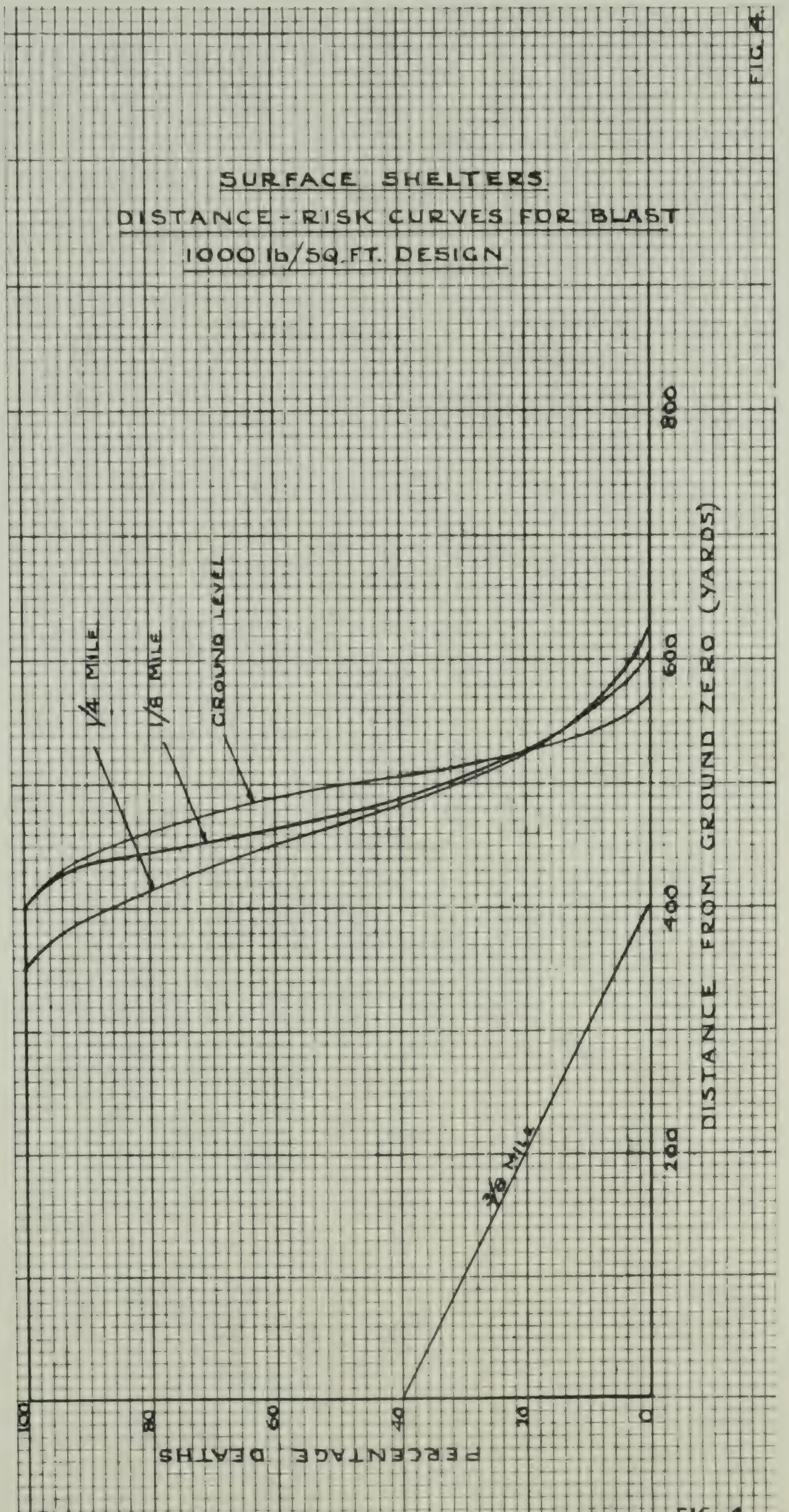
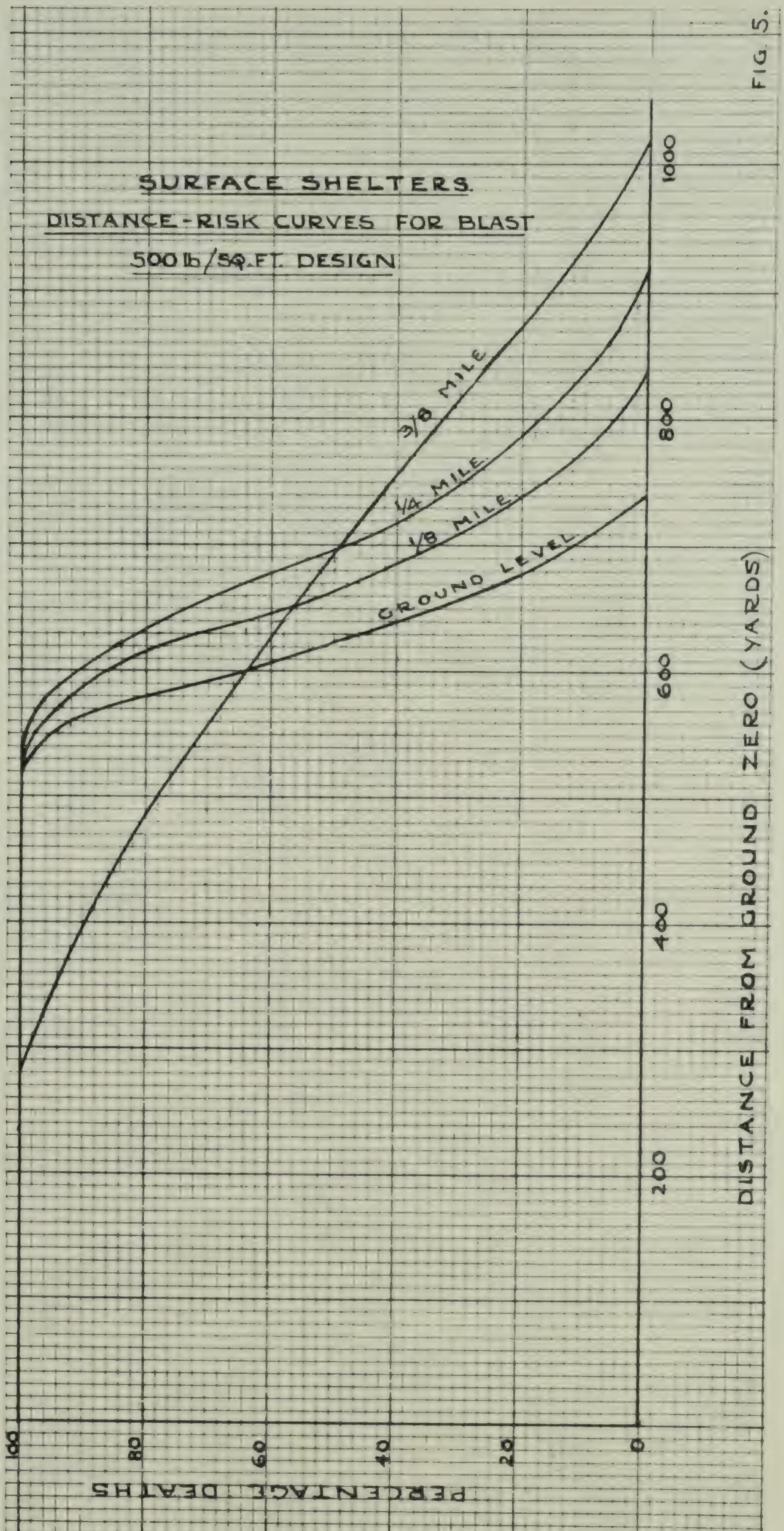

SURFACE SHELTERS
DISTANCE - RISK CURVES FOR BLAST
1000 lb/SQ.FT. DESIGN
1/4 MILE
1/8 MILE
GROUND LEVEL
3/8 MILE
DISTANCE FROM GROUND ZERO (YARDS)
200
400
600
800
PERCENTAGE DEATHS
100
80
60
40
20
0
FIG. 4

FIG. 4


SURFACE SHELTERS.
DISTANCE-RISK CURVES FOR BLAST
500 lb/SQ.FT. DESIGN
3/8 MILE
1/4 MILE
1/8 MILE
GROUND LEVEL
1000
800
600
400
200
DISTANCE FROM GROUND ZERO (YARDS)
100
80
60
40
20
0
PERCENTAGE DEATHS
FIG. 5.
FIG 5.

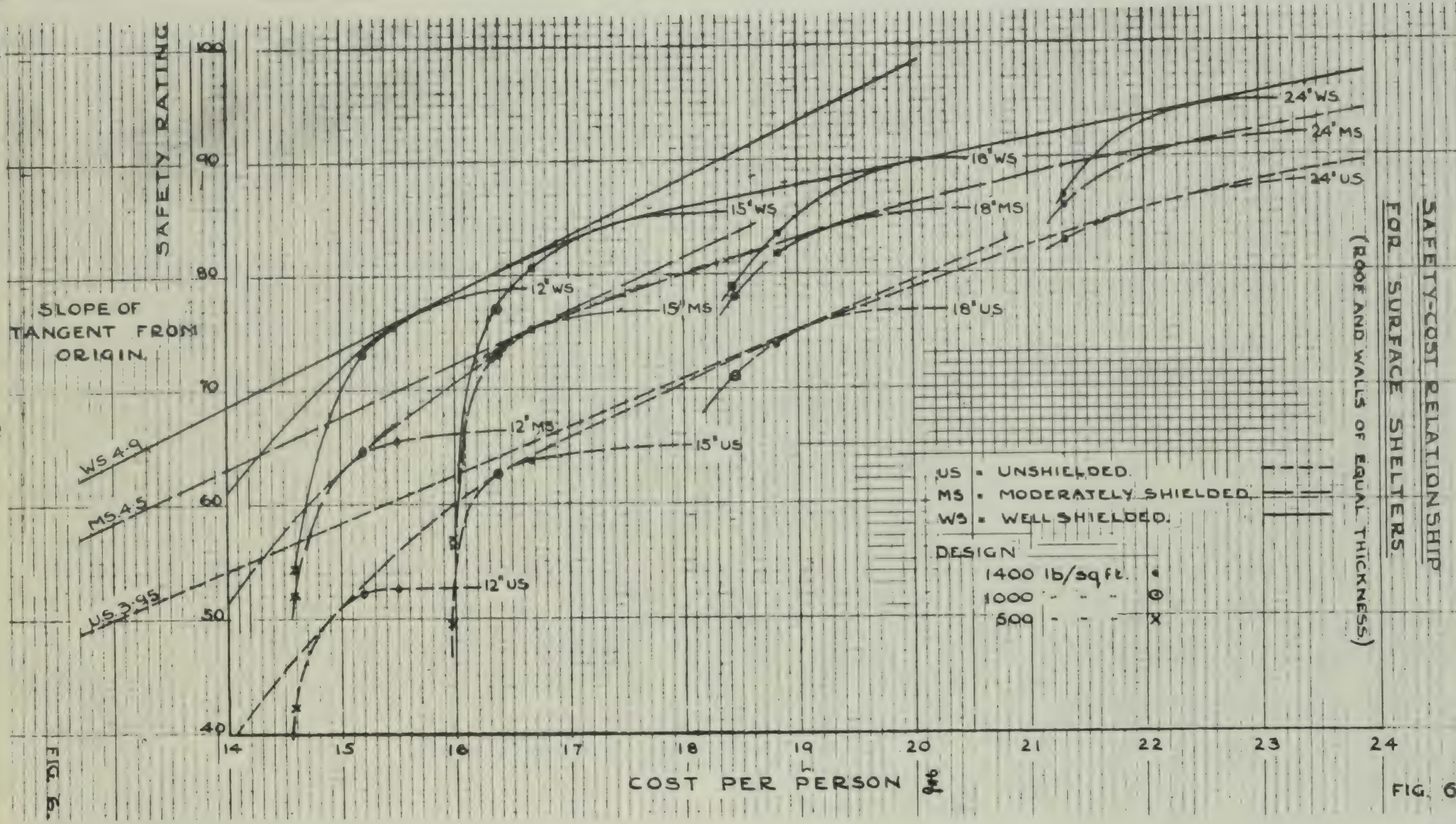

SAFETY-COST RELATIONSHIP
FOR SURFACE SHELTERS
(ROOF AND WALLS OF EQUAL THICKNESS)
SAFETY RATING
COST PER PERSON £
SLOPE OF TANGENT FROM ORIGIN.
WS 4.9
MS 4.5
US 3.95
24" WS
24" MS
24" US
18" WS
18" MS
18" US
15" WS
15" MS
15" US
12" WS
12" MS
12" US
US = UNSHIELDED.
MS = MODERATELY SHIELDED.
WS = WELL SHIELDED.
DESIGN
1400 lb/sq ft. •
1000 - - - ⊙
500 - - - X
FIG. 6.

FIG. 6.

(19908)

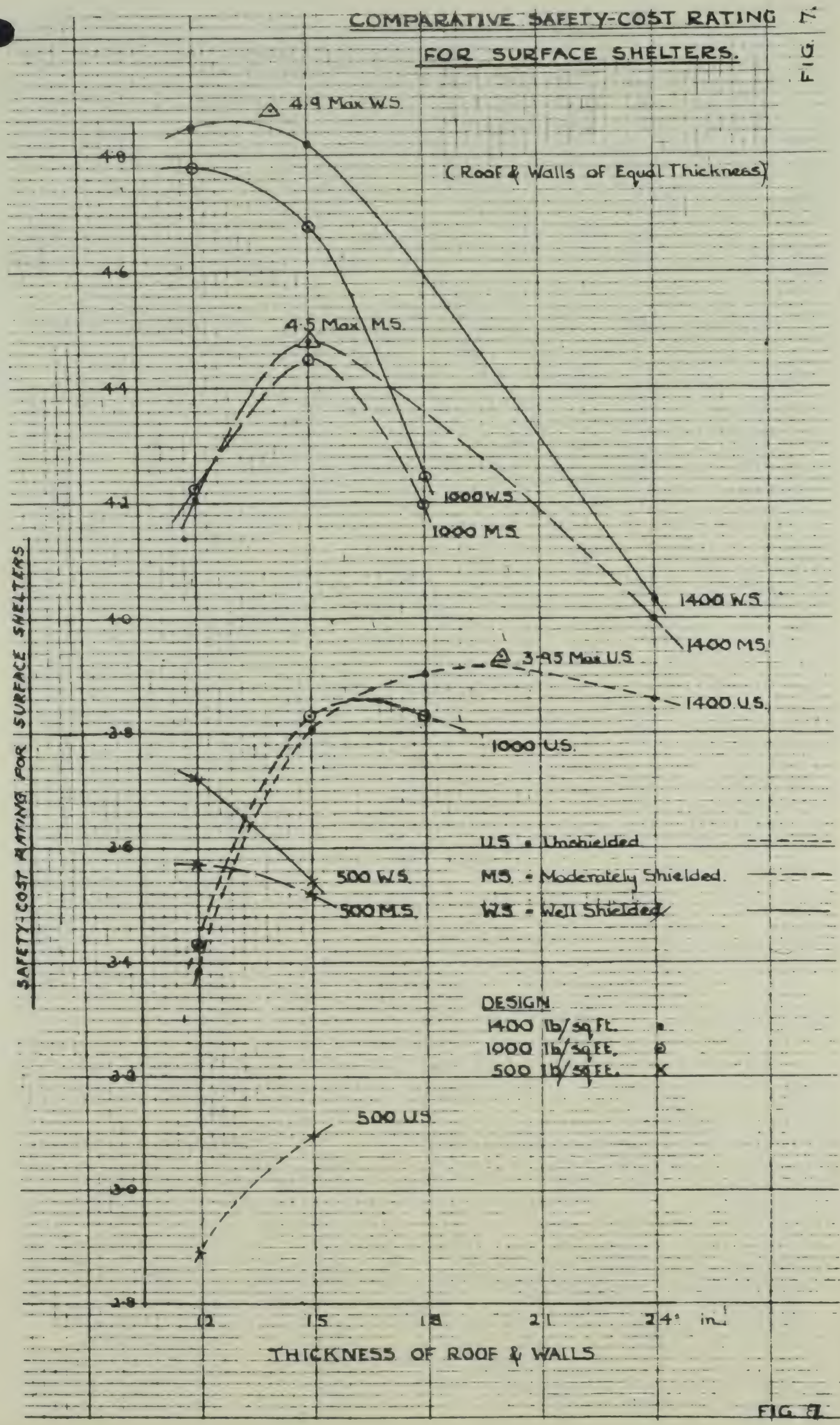

COMPARATIVE SAFETY-COST RATING
FOR SURFACE SHELTERS.
FIG. 7.
4.9 Max W.S.
(Roof & Walls of Equal Thickness)
4.5 Max M.S.
1000 W.S.
1000 M.S.
1400 W.S.
1400 M.S.
3.95 Max U.S.
1400 U.S.
1000 U.S.
U.S. = Unshielded
M.S. = Moderately Shielded.
W.S. = Well Shielded
500 W.S.
500 M.S.
DESIGN
1400 lb/sq.ft.
1000 lb/sq.ft.
500 lb/sq.ft. X
500 U.S.
SAFETY-COST RATING FOR SURFACE SHELTERS
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
12
15
18
21
24 in.
THICKNESS OF ROOF & WALLS

FIG. 7.

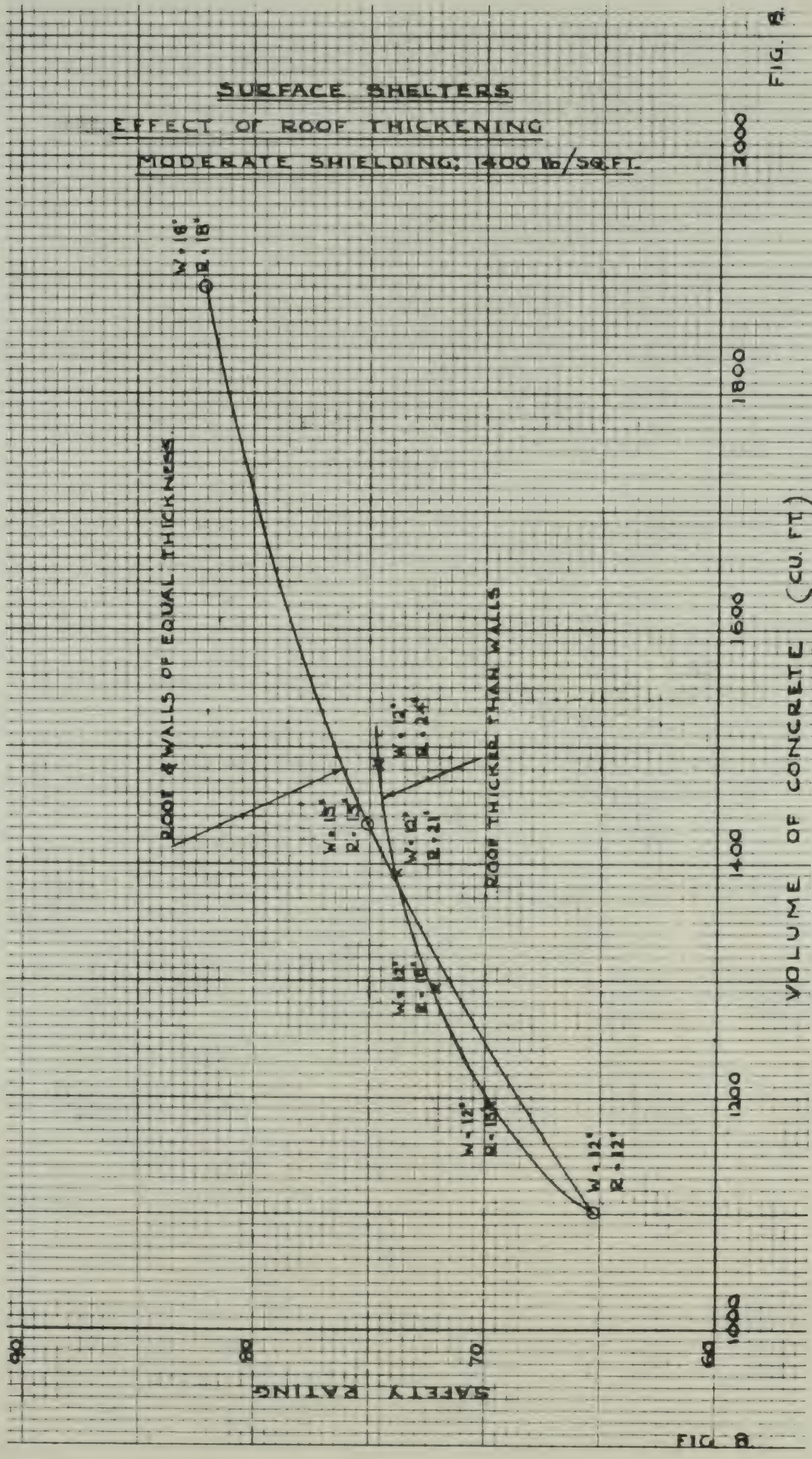

SURFACE SHELTERS
EFFECT OF ROOF THICKENING
MODERATE SHIELDING: 1400 lb/SQ.FT.
ROOF & WALLS OF EQUAL THICKNESS
ROOF THICKER THAN WALLS
W. 18"
R. 18"
W. 15"
R. 15"
W. 12"
R. 24"
W. 12"
R. 21"
W. 12"
R. 18"
W. 12"
R. 15"
W. 12"
R. 12"
SAFETY RATING
90
80
70
60
VOLUME OF CONCRETE (CU. FT.)
1000
1200
1400
1600
1800
2000
FIG. 8.

FIG. 9.

SURFACE SHELTERS.
SAFETY-COST CURVES FOR 8 N BOMB
MODERATE SHIELDING

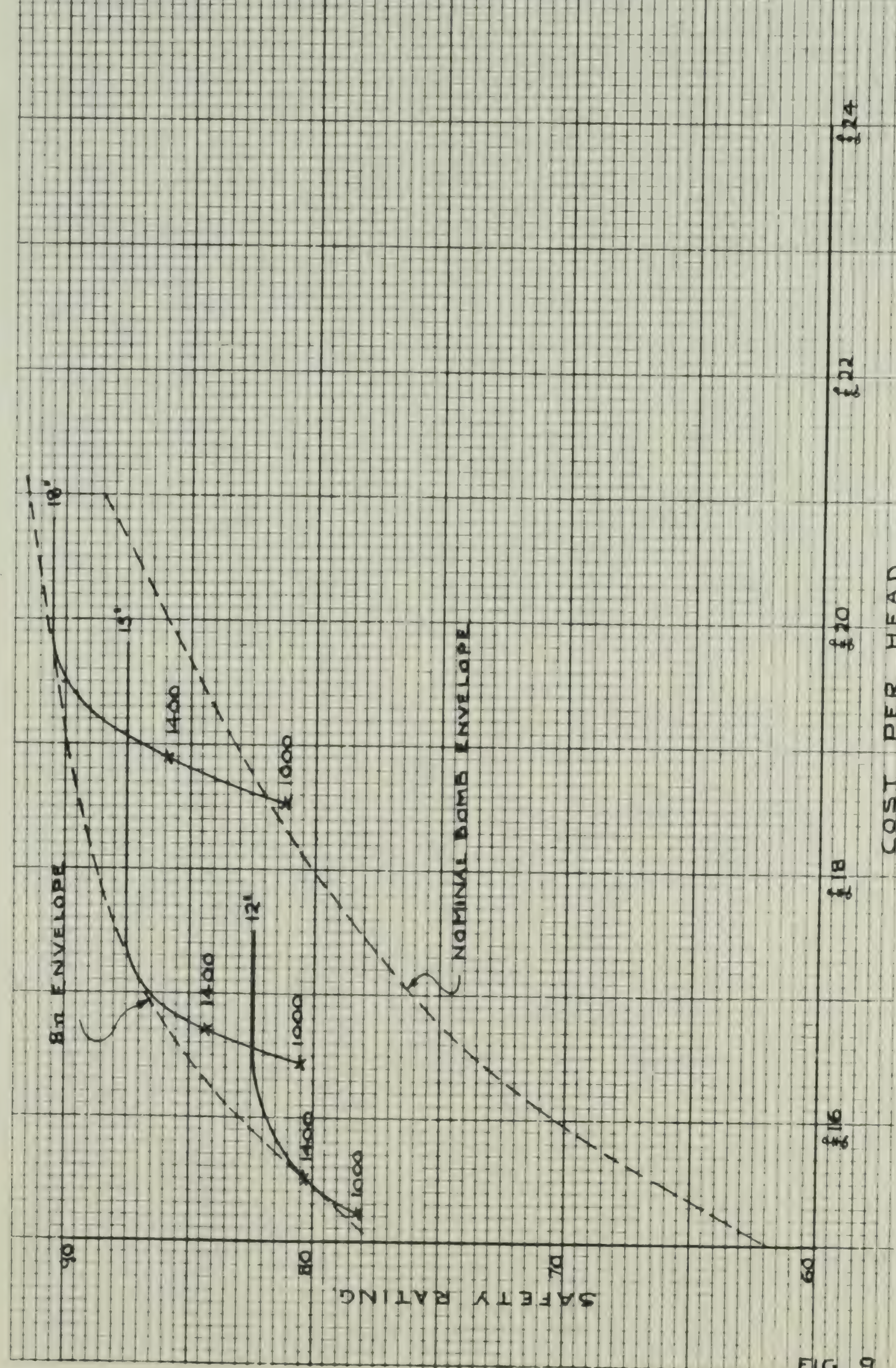


FIG. 9.

TRENCH SHELTERS

DISTANCE-RISK CURVES FOR BLAST

250 lb/SQ.FT. DESIGN.

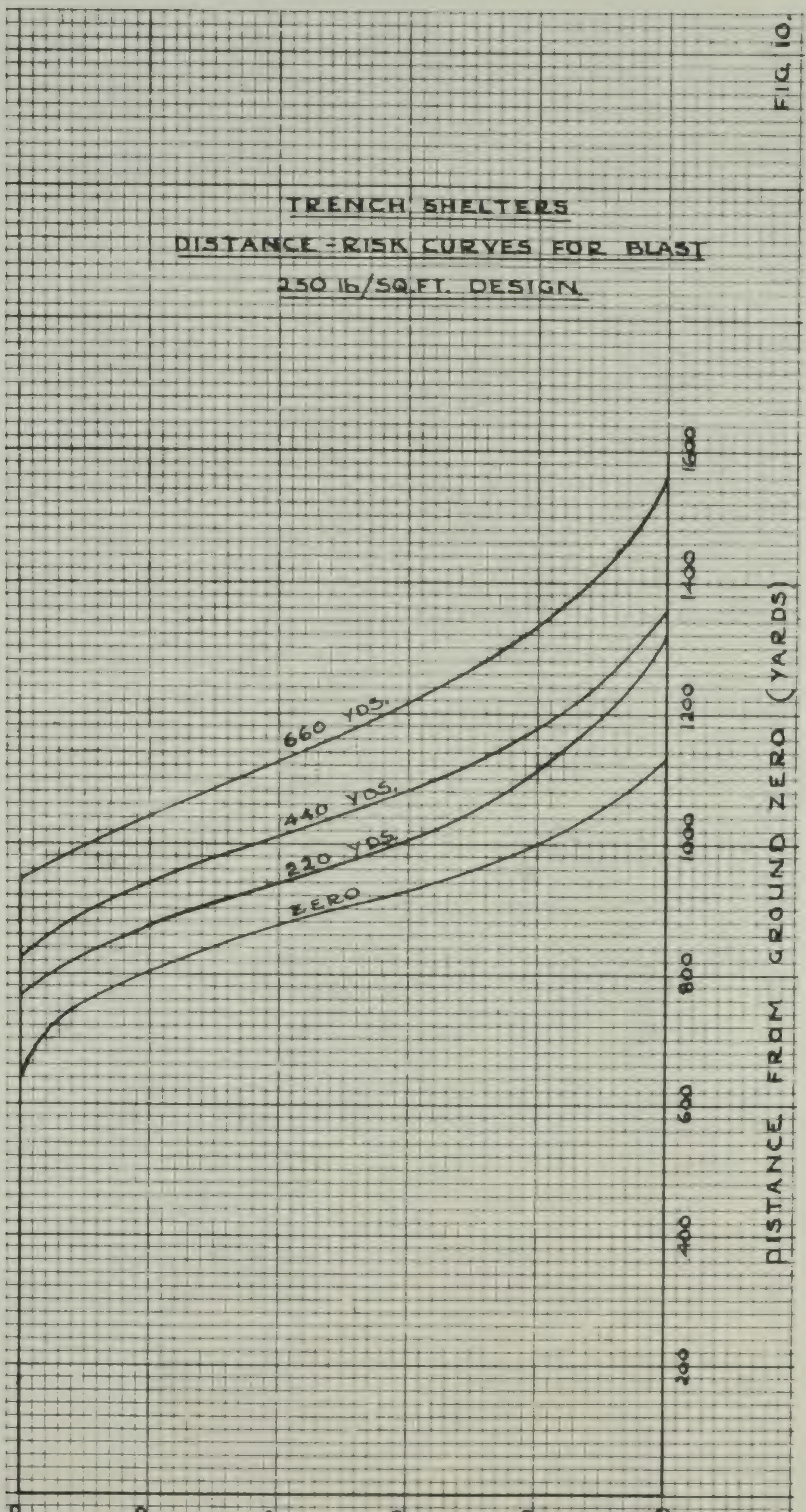
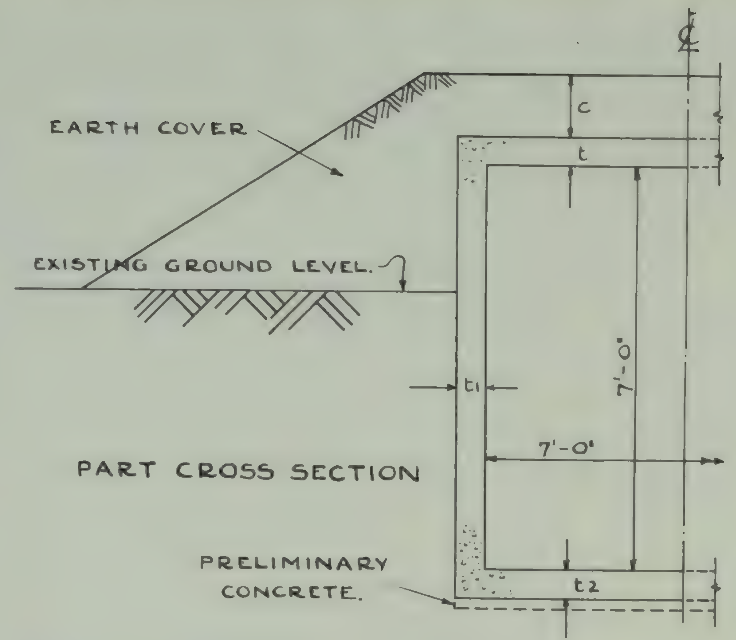
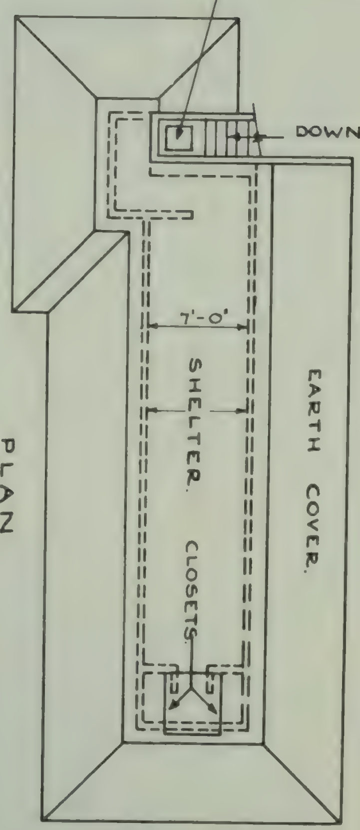


FIG. 10.

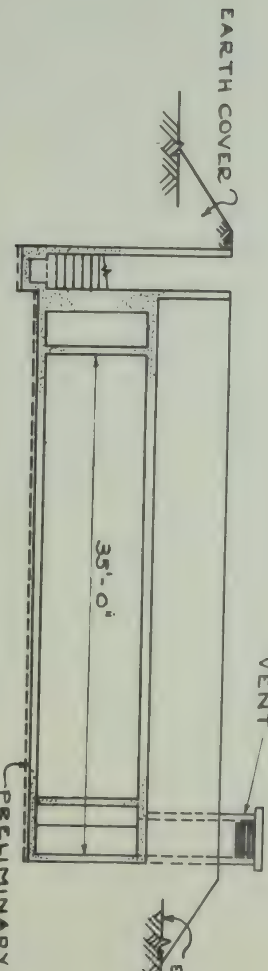


PART CROSS SECTION

CASE No.	BLAST LOAD	ROOF THICKNESS t (IN)	WALL THICKNESS t1 (IN)	FLOOR THICKNESS t2 (IN)	EARTH COVER 'C' FEET.	WT. OF REINFORCEMENT PER FT. RUN OF SHELTER (LB)	TOTAL WT OF STEEL IN SHELTER (LB)
1	1400	7½	5	5	1·0	46·9	2110
	1000	6	"	"	"	41·3	1896
	500	5	"	"	"	35·6	1701
	250	"	"	"	"	33·0	1606
2	1400	7½	5½	5½	2·0	51·7	2367
	1000	6	5	5	"	51·3	2352
	500	5	"	"	"	47·9	2237
	250	"	"	"	"	"	"
3	1400	7½	6	6	3·0	55·2	2593
	1000	6	"	"	"	53·1	2523
	500	"	"	"	"	50·0	2413
	250	"	"	"	"	"	"
4	1400	7½	6½	6½	5·0	65·6	3115
	1000	6½	"	"	"	63·0	3025
	500	"	"	"	"	"	"
	250	"	"	"	"	"	"



PLAN



SECTIONAL ELEVATION.

TRENCH SHELTERS.

FIG. 11.

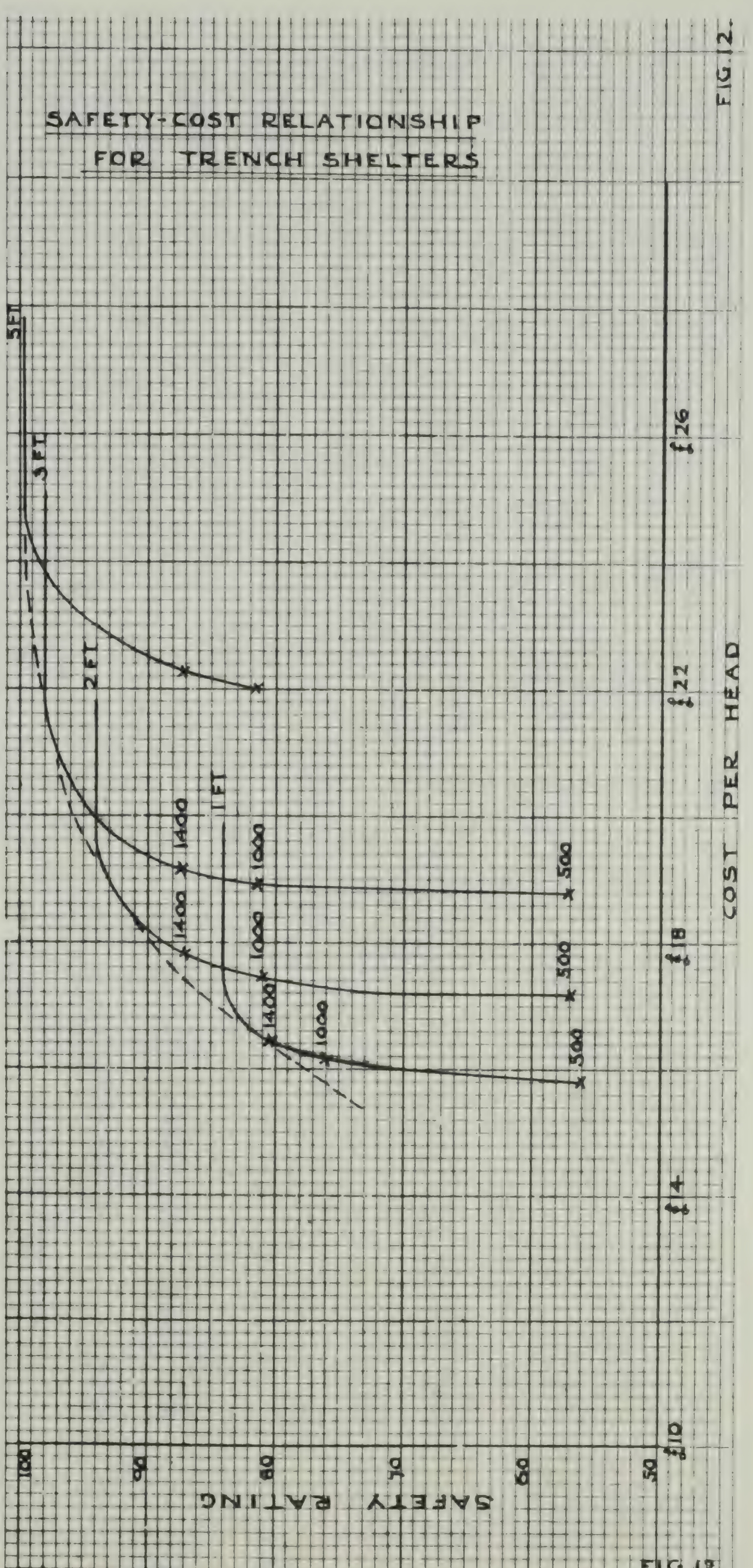

SAFETY-COST RELATIONSHIP
FOR TRENCH SHELTERS
5 FT
3 FT
2 FT
1 FT
1400
1000
500
£10
£14
£18
£22
£26
COST PER HEAD
100
90
80
70
60
50
SAFETY RATING

FIG. 12.

DEFE 13/45

DEFE 1

Private Office No. :—

1954

CONFIDENTIAL

MINISTRY OF DEFENCE

PRIVATE OFFICE

Subject :—

Thermo-Nuclear Weapons
"Fall out" - Strath Report.

This file contains the Minister's personal papers on the above subject. Departmental action should be recorded on the appropriate official file and not on this file. This folder may not circulate outside Private Office without permission of the Private Secretary.

RELATED PAPERS.

PE. 954/2 Public pronouncements on the effect of thermo-nuclear weapons

1963 Long term defence policy

Atomic proving ground

Thermonuclear proving ground

Regulation & limitation of nuclear tests.

RECORDS

B/F November 1955

1981

SR(1981)

Home Office,
Whitehall, S.W.1.

30th July, 1956.

Dear Forward,

You will remember that on 11th June your Minister wrote to mine suggesting that the implications of the proposed Memorandum on Public Control under Fall-out Conditions were of such importance that Cabinet approval should be obtained for its issue.

My Secretary of State agreed with this view and accordingly arranged for a suitable covering paper to be prepared. We were a little hesitant about circulating the paper while the recent discussions about the future level of home defence expenditure were going on, and it is only within the last day or two that we have been able to clear a paper for circulation. Major Lloyd-George has approved the paper, but has instructed that, as there is no possibility of it being taken before the recess, we should hold it over until a later date.

In accordance with his instruction I shall be arranging with the Cabinet Office for the paper to be circulated in due time, but I thought you might like to have this note about how the matter stood.

I am sending a copy of this letter to Gauld and to Perrin, whose respective Ministers are parties to the draft paper.

Yours sincerely,

T. S. Forward, Esq.

E.R.

N.B.F.
I am ready to discuss with Home Secretary. I think of this that we ought to mention it to the P.M. WM 6/vi

Minister.

PO 1964

The Home Secretary wants to have a word with you about the political wisdom of issuing the memo. on radioactive fall-out to local authorities. I asked the Chiefs to comment on the memorandum [illegible] paper for you.

[illegible] 2/vi.

S E C R E T

RCC/56/164

MINISTER OF DEFENCE

The object of the scheme of control outlined in the attached Home Office memorandum is to reduce the number of casualties from radiation sickness in the areas covered by fall-out after a thermo-nuclear attack.

2. The scheme proposes that in a fall-out area the public should remain under cover, preferably in special fall-out refuges constructed in their houses, for the first forty-eight hours, during which the rate of radio-activity would decay to one-hundredth of the rate at one hour after the bomb had burst. Thereafter the permissible movement would depend on the intensity of the residual radio-activity. For this purpose it is proposed that the fall-out area should be divided into four zones, W, X, Y, and Z; zone W covering the fringes of the fall-out area and zone Z being the area of highest radio-active contamination. After forty-eight hours complete freedom of movement should again be possible in zone W, but in zone Z movement in the open would still be dangerous, but it would be possible to evacuate the population from the zone without exposing them to an excessive dose rate. The memorandum outlines the arrangements for giving warning of radio-active fall-out and the procedures for establishing the four zones within the fall-out area and of notifying them to the public. It also discusses how the evacuation of zone Z might be undertaken after the forty-eight hour period.

[illegible] 4/vi

N.B.F.
1. M.R.C. [illegible]
2. Defence Cabinet [illegible]
[illegible]
WM 8/vi
[illegible]

3. The Home Secretary wants to issue this memorandum to the local authorities but he would like first to discuss with you the advisability of doing so at the present time.

E.R.

4. I suggest that there can be no objection to putting this proposed scheme to the local authorities. The scheme is at present only provisional and many aspects would in any event need to be discussed with the local authorities before more detailed arrangements could be formulated.

5. Despite the present pressure to reduce civil defence expenditure, it is surely unthinkable that we shall decide as a result of the present review of defence policy to wind up our civil defence services immediately. Such action would be liable to cause almost as severe a shock to N.A.T.O. as a unilateral decision to withdraw our forces from the continent. For the time being at least our policy must be to continue with civil defence, but at a lower tempo reflecting the reduced threat of war. During this period we must keep civil defence planning and training up to date. If the local authorities were to be given the impression we had lost all interest in civil defence, then either the civil defence services would begin to fade away or we should be faced with a demand for expensive measures to reinvigorate them.

6. This memorandum does not per se create a new demand for expenditure on civil defence. Without it, the local authorities are liable to be held up in developing their planning and training.

7. I understand that the Home Office also have in mind that this memorandum might be made available to the general public as part of the programme of education referred to in paragraph 102 of the Statement on Defence, 1956. I cannot see that this is called for, especially since the scheme of control is still only provisional. It is no use trying to educate the public in rather detailed plans of this kind in the present atmosphere. Admittedly, the issue of this memorandum to local authorities may well result in the outlines of the scheme becoming known to the public, but this would not matter.

E.R.

8. From the point of view of general information to the public about the effects of fall-out, the memorandum does not in fact add significantly to the information that has already been published in the pamphlet on nuclear weapons which was issued earlier this year.

R.C. Clarke

Cabinet Office, S.W.1.
30th May, 1956

Author: Dr John McAulay, UK Home Office Scientific Adviser's Branch (see draft in their files in Nat. Arch.)

11th May, 1956

HOME OFFICE - SCOTTISH HOME DEPARTMENT

RADIOACTIVE FALL-OUT

Provisional Scheme of Public Control

NOTE: UK Home Office in 1956 published this as unclassified open: Manual of Civil Defence, vol. 1, Pamphlet 2. However, under ignorant political (Ministerial) demands, the reprint in 1957 was re-classified as "Restricted" for political fear it would lead to demands for increased interest in the credibility of civil defence, and further expense (though this was a trifle compared to nuclear expenditure!). (This exasperated CD Corps instructor John B. Cook into resigning in protest.)

IV. CATEGORISATION OF ZONES.

17. The basis proposed for the scheme of control is the categorisation of fall-out areas into zones of radiation intensity in relation to each of which a drill to be observed by the public can be prescribed. In this and the succeeding sections the zones are described. The method of establishing them and the bearing of the proposals on the responsibilities of the civil defence and other services are considered in a concluding section.

18. The letters W, X, Y and Z would be used to identify four kinds of zone. The zone category would, for the most part, be determined by the dose rate in roentgens per hour (r.p.h.) at 48 hours after burst, i.e., as a general rule 1/100th of the rate at 1 hour. This basis of definition is proposed to be adopted chiefly for the reasons given in paragraphs 4 and 5, but there are also the following grounds for its adoption:

(i) the dose rate at 1 hour would, over large parts of the fall-out area, be a theoretical rather than a practical concept, since the fall-out would not have travelled far in the first hour and at most would only be complete close to ground zero;

(ii) generally, except in Zone W (see next Section) or in the damaged area, no action out of doors is required or should be encouraged, in the fall-out area within the first 48 hours;

(iii) there would be advantages in basing action in the fall-out area on a predicted dose rate at 48 hours which could be verified from instrument readings at the time. This would provide a safeguard against any variation in the decay rate and a check on predictions based on the dose rate at 7 hours (1/10th of the rate at 1 hour) which would be used for the provisional determination of boundaries.

19. The determination of fall-out zones and the institution of the control plan would be a process independent of operations by the civil and military forces to deal with casualties and damage in the area close to ground zero. Such operations, which would call for a balancing of the radiological hazard to the participants against the results they might be able to achieve in a given time, could best be conducted on the basis of actual dose rates measured at the time.

20. As explained in paragraph 7 any estimate before the event of the area which would be affected by fall-out can at best be speculative; it is clear, however, that it is necessary to think in terms of some thousands of square miles. The data published in respect of the American nuclear weapon test in March, 1954, refer to an area of 7,000 square miles in which survival might have depended on prompt evacuation of the area or upon taking shelter and to an area of 14,000 square miles in which a cumulative dose in the open of 100 roentgen or more was recorded in the 24-48 hours after the detonation. The control scheme, if it is to achieve its object of keeping sickness to a minimum, would have to operate in the initial stages in respect of even lower doses than this. The area affected by fall-out from a megaton weapon attack would probably be of such dimensions as rarely to develop its full extent over the land surface of the United Kingdom. A ten megaton bomb might well result in an actual dose rate of 0.3 r.p.h. being measured up to 1,000 miles from ground zero and the contaminated area might at its widest part be 80-100 miles across. Within this area the territory in which control measures would need to be observed after the initial 48 hour period (Zones X,Y and Z) might still be of the order of 500 x 40 miles.

21. The following table gives a summary definition of the zones and the recommended and permissible action in them:-

TABLE FOR INCLUSION IN PARAGRAPH 21.

Zone	Definition of Zone Boundaries	Range of Cumulative Dose in open at 48 hours	Summary of permissible and recommended action	Range of Cumulative Doses assuming observance of control rules.
W	Outer: Limit of area placed under "Black Warning" (See Footnote). Inner: 0.3r. at 48 hours	Up to 80 r.	Complete release from refuge as soon as dose-rate falls to 0.3 r.p.h. or, if the rate had not reached that figure, when fall-out is complete.	At 48 hours 2 r.
X	Outer: 0.3r. at 48 hours Inner: 3r. at 48 hours.	80 - 800 r.	Qualified release from refuge after 48 hrs. - Indoor workers to follow normal occupations, but not to exceed 4 hrs. per day in the open. Outdoor workers to work half shifts for next five days. At the end of this period the zone would be normal, except that all would be advised to be out of doors as little as possible and not in any case to exceed 4 hrs. per day in the open for the next three months.	At 48 hrs. 2 - 20 r. Next 5 days 6 - 50 r. Next 4 wks. 12 - 120 r. Next 2 mths. 14 - 145 r.
Y	Outer: 3r. at 48 hours. Inner: 10r. at 48 hours.	800 - 2,800 r.	Release from refuge under stringent control after 48 hrs. For the next 12 days people should not leave their refuge for longer than necessary. Time in the open should not exceed 2 hrs. per day and time under cover, but not in refuge, a further 8 hrs. On this basis essential indoor workers should be able to get to their places of work, but outdoor work would remain suspended; a relaxation would be possible after the first fortnight and further easement in another three weeks. For the rest of the first year, however, people in this zone should not exceed 4 hrs. a day in the open.	At 48 hrs. 20 - 70 r. Next 12 days 50 - 170 r. Next 3 wks. 75 - 260 r. Next 2 mths. 95 - 530 r.
Z	10r. at 48 hours.	Above 2,800 r.	All movement outside refuge accommodation in this zone would be dangerous. People should remain in refuge until instructions for clearance are given - they should then leave the zone by the quickest available route if they have means of transport or wait in their refuge to be collected if they have not. The clearance operation might start after 48 hrs. and removal from the zone would be for at least 3 months.	At 48 hrs. - Above 70 r.

After 48 hours Zone W would for public control purposes have disappeared. Its outer boundary would have moved during that period to coincide with the outer boundary of Zone X. The true outer boundary of the zone would be the contour at which the dose rate in the open was never in excess of 0.3 r.p.h. which is, for practical purposes, the lowest reading which can be reliably taken with the existing radiac survey instrument. In practice the initial Zone W boundary would be defined in terms of the boundaries of a series of warning districts on the flanks of the fall-out. The question of defining an area extending in some places beyond Zone W in which there might be an agricultural hazard is being studied.

V. ZONE W

22. Characteristics of Zone W. Zone W would cover the fringes of the fall-out area. It would be potentially a very extensive area indeed, but in the United Kingdom would be unlikely to develop its full extent before reaching the coast. Its outer boundary would initially be constituted by the limits of the warning districts in respect of which a warning message "Black" was issued signifying imminent danger of fall-out; its inner boundary would form the outer boundary of Zone X. During the first 48 hours Zone W would contract as the dose rate fell below 0.3 r.p.h. After 48 hours the zone would cease to exist for public control purposes, though an agricultural hazard might remain.

23. The proposals for Zone W are designed to ensure that no one would get a short term dose of more than 6 r. even if he spent the whole of the next 12 hours in the open after being released; it is not proposed to impose any greater restriction on anyone than would be consistent with the attainment of this objective. Given good discipline in the first 2/3 days, all the people in this zone would be able, without restraint, to play their full part in the work of restoration, decontamination and recuperation. The aim would be progressively to release them all at the earliest moment it was safe to do so. After release they would be able to regard themselves as unaffected by radiation and would be able, if required, to enter and work in more heavily contaminated areas on the same terms as people not affected by fall-out at all.

24. Establishing the outer boundary. The first problem would be to establish an outer boundary and to guard against traffic crossing the boundary and penetrating into the fall-out area. The necessary action would have to be taken outside any area to which the "Black" fall-out warning was given. As soon, therefore, as a warning district received the "Black" warning it would be for all the wardens posts immediately outside the boundary (except any which were themselves already under the "Black" warning or received it concurrently) to put up notices on the boundary of the "Black" district bearing the legend:-

"DANGER - FALL-OUT"

25. The technique for carrying out the posting of warning notices will require to be worked out both generally and in detail. At this stage it is sufficient to say that through roads, especially trunk roads, would receive priority of attention. The exhibition of notices would not entail the setting up of road blocks or the risk of exposure of personnel to radioactivity. The purpose of the notices would be informatory, i.e. to ensure that no person or vehicle proceeded further along the road in ignorance of the danger they might run. This procedure would have to be followed whether or not the posts on whom the duty fell were themselves under the "Red" or "Grey" warning.

26. Contraction of Zone W. By the means outlined in paragraph 25 a provisional control line would be established on both flanks of the fall-out area along the boundaries of the warning districts under the "Black" warning. During the next 48 hours the objective would be systematically to release the area within the control line up to the boundary of Zone X and to do this as rapidly as possible. This would be achieved by adding individual post areas or groups of post areas to the free zone beyond the provisional control line as soon as it became safe to do so. The general criterion for this purpose would be when the radioactivity reading for a particular area, or areas, had fallen to 0.3 r.p.h. As the radioactivity decayed, the true 0.3 r.p.h. line would move continuously towards the fall-out axis at a speed which is, however, unlikely to exceed ½ mile in an hour; it would move even more slowly where the contours were

closest together near to ground zero. The Zone W boundary would contract in rough conformity with this movement (see paragraphs 50-52).

27. Release procedure. For a variety of reasons, which would apply with even greater force to the higher intensity zones, release of the public from restrictions after fall-out had occurred could not be effected by a general siren signal. When an area was released, it would be necessary to ensure that everybody in it was made aware of the conditions applying to that area and of such continuing precautions as they should, in their own interest, observe. In the main, this would have to be done by wardens on a basis of house to house notification, though in some cases it might be possible to speed up the process e.g., by the use of public address equipment mounted in vehicles.

28. The inhabitants of a released area in Zone W would be told that they had been in such a zone, that they were now free of all restriction, that they were unaffected by radioactivity, but that they should conform with the public notices marking the limits of the free zone. Wardens would initiate release action on bein authorised to do so by their local control.

VI. ZONE X

29. Characteristics of Zone X. This would be a zone of comparatively light contamination; its extent would, however, be considerable, perhaps 450/600 miles long and 35/50 miles wide for a 10 megaton weapon. It would be a zone in which, once the period of 2/3 days after burst had elapsed, something closely approximating to normal working conditions would have to be restored forthwith: the area should cease to be a liability on the rest of the nation, except perhaps as regards agricultural products. The dose rate in the area, which would have ranged from 30 r.p.h. up to 300 r.p.h. at 1 hour after burst, would have fallen to between 0.3 r.p.h. and 3 r.p.h. The dose received by people in the area at the end of 48 hours, assuming they had spent this time in refuge, would have been between 2 r and 20 r. For the rest of the first week (i.e., the next five days) they should not spend more than 4 hours per day in the open, but freedom for up to 4 hours should enable the great majority of people to go about their normal business. For the remaining 20 hours of each day they should be advised to spend as much time as possible in their refuge, but in any case indoors. Provided they remained under cover, their dose would not be seriously increased. At the end of the first week people in Zone X would be freed from restraint. If the time such people would, on average, thereafter subsequently spend in the open is put at hours per day, the cumulative dose of people in the zone would, assuming a protective factor of 40 for their refuge, lie between 14 and 145r. at the end of three months with a possible further increase of 2 - 25r. during the remainder of the first year. These figures have been calculated on a basis which excludes further possible reduction by the physical removal of contamination, e.g. down the drain whether by weathering or decontamination; it is accordingly reasonable to assume that very little, if any, radiation sickness would occur in the zone, but there would be some long term effects. It is possible that the cumulative doses would be reduced if effective decontamination could be undertaken both by householders and the public authorities, but there are considerable practical difficulties about this.

30. Further consideration will need to be given to the position of outdoor workers in the zone, many of whom perform duties of first importance - agricultural workers, police, transport staffs, etc. Strict control of their hours of work after the general release took place would be an obvious requirement.

31. Establishment of the boundary and release procedure. The outer and inner boundaries of Zone X would be determined in accordance with the procedure described in Section IX of this memorandum, and the roads crossing the inner boundary (which would also be the outer boundary of Zone Y) would require to be marked after the lapse of 48 hours in the same way as described in paragraph 24. The marking boards would be more mandatory in character, e.g.,

"DANGER - FALL OUT

ZONE Y STARTS HERE

NO ENTRY"

When the word for release was given, wardens would have to use the time they were permitted to spend in the open notifying the inhabitants of their areas that they were in Zone X; that they could leave their houses for limited periods, but should

spend as much time as possible indoors under cover either at home or at their place of work. For the next five days they should avoid being in the open as far as possible and in no case for more than 4 hours a day. They should not regard themselves as available for work in the higher intensity Zones Y and Z, but could play a very significant part of preparing aid for those in Zone Y. Any household who wished to leave the zone and had the means to do so could not be prevented from moving, but they should be warned of the congestion likely to be found elsewhere and of the dangers of being unable to find adequate shelter in the event of another attack. They should be encouraged to recognise the greater claim of others to leave the innermost zone and to exercise restraint by staying put.

VII. ZONE Y

32. Characteristics of Zone Y. In this zone stringent precautions would be essential; initial dose rates in the open might have been as high as 1,000 r.p.h. Though much smaller than Zone X, it would still cover a large area; a 10 megaton weapon might give rise to a Zone Y up to 20 miles wide and some 200 miles long. Even after 48 hours, the dose rate in the open would range between 3 r.p.h. and 10 r.p.h. and the inhabitants of the zone (who, if in refuge affording a protective factor of 40, would already have taken between 20 and 70r) would, if they were not to become sick, have to act with discipline and discretion. Virtually their only concern for the whole of the first fortnight would be with their own radiological safety. For this period they would need to restrict the time spent out of doors to, say, 2 hours per day at most, and the time which they spent out of their refuge but under cover to a further 6 hours per day. Even after 14 days, they would need to continue to remain under cover as far as possible, and should not in any event be in the open for more than 4 hours per day for the next three weeks; and 6 hours per day for the rest of the first year. Assuming observance of such a discipline the cumulative dose of people in the zone would lie between 95 and 330r. at the end of three months and between 125 and 430r. at the end of the first year.

33. After the first 2/3 days, Zone Y would begin to come to life again. There should not be much sickness in the zone having regard to the time over which the dose of 20 - 70r. would have been spread. The bulk of the people in the zone must, however, continue to stay within doors and be prepared to nurse such of their number as fall sick without aid or advice other than such general guidance as might have been issued beforehand or be relayed to them by broadcast. It would be important to ensure that the permissible two hours in the open was turned to good account. Within households there would be scope for spreading the risks by sending out individual members to perform necessary services for all. Careful organisation would be required to avoid more people emerging at the same time, e.g., to get food, than could be attended to promptly. It is to be hoped that many, if not most, of the people would contrive to spend less than the allowed time in the open; they should not in any event go far from their homes or billets. Properly utilised, the two hours should none the less enable them to exist under tolerable conditions. It would permit visiting of near neighbours and short journeys to get essentials, preferably by bicycle or car. Only the most urgent of outdoor tasks would be able to be performed by people already in the zone, but key personnel required as reliefs for the operation of essential services would be able to report for duty provided protection was available for them at their places of work.

34. As with Zone X, people should be discouraged from leaving the zone. The keynote of policy should be that people in the zone were safe, provided they were sensible and observed the recommended precautions. The departure of those who had the means to take themselves out of the area could, however, hardly be prevented; indeed it might be that some arrangements for removing young children with their mothers would prove to be feasible. The transit dose of radiation for a journey by car from the inner contour of the zone after 48 hours would amount to about 3 r.

35. Establishment of the boundary and release procedure. This would not differ in principle from the corresponding action in Zone X. Each warden would have less time in which he could be expected to play his part in establishing contact with householders to give them guidance on the local situation. The arrangements for marking the inner boundary of the zone (i.e.,the beginning of Zone Z) would be of less urgency and importance, than in the outer zones.

VIII. ZONE Z.

36. Characteristics of Zone Z. The dose rate in this zone would have been 1,000 r.p.h. or more at one hour after burst; at 48 hours it would still be 10 r.p.h. in the open at the outer contour. Assuming people in the zone to have had the benefit of a protective factor of 40 in their refuges, the minimum cumulative dose would be about 70r. and much higher doses would have been received in parts of the zone. On its outer fringes, the zone would contain people for whom there would be good hope of escaping any serious effects. Further towards the fall-out axis and closer to ground zero, sickness, of which symptoms might be beginning to appear after about 48 hours, would be general. In the inner part of the zone, especially in the heavily damaged area towards ground zero, lethal doses of radiation would have been received by some, and the entire population would be suffering various degrees of incapacity. The chances of ultimate survival of many of these might be slender.

36A. The 10r at 48 hours contour might extend for a distance of 70 - 100 miles from the ground zero of a 10 megaton bomb; it might enclose an area up to 12 miles wide. These figures, like other zone dimensions given in this memorandum, need to be treated with reserve; they provide an indication of the scale on which control operations would have to be conducted - no more. In the case of Zone Z there are special grounds for emphasising this factor: not only must allowance be made for the variables affecting fall-out mentioned in paragraph 7, but decisions taken in the aftermath of the attack might critically affect the determination of the zone boundary. The action to be taken in respect of the zone, as the following paragraphs show, would be drastic, and there would be a consequent need for flexibility in the classification of post areas on or near the boundary e.g. by the adoption in places of another (higher) contour. The weight of the enemy's attack and the resulting situation elsewhere in the country at the time might be the deciding factors.

37. Procedure in (and in relation to) Zone Z. The discipline proposed in paragraphs 32 and 33 in respect of Zone Y is regarded as the most severe with which substantial compliance by a population of all ages could be expected. It follows that any attempt to organise communal life in Zone Z would fail and that wholesale clearance of the zone must be undertaken, if sickness and death were not to overtake the great majority of people in it. After 48 hours radioactivity would continue to decay, but at a relatively slower rate. Since people could not remain indefinitely in the zone, the sooner the process of their removal could be started after 48 hours the better.

38. Clearance of Zone Z would be a combined operation. There could be no way of knowing in advance how many people would have to move, but they are likely to be numbered in 100,000's. The broad scope of the operation and its timing together with any related broadcasting of information would have to be dealt with at regional headquarters where the military, police, transport and civil defence welfare interests would be represented. Its detailed planning would have to be organised in sectors each concerned with clearing a particular part of the zone. Its efficient conduct would call for the collaboration of those inside the zone with their rescuers.

39. No one could be sent in to the zone until 48 hours had elapsed; the interval must, however, be used for making preparations to bring all available resources to bear as soon as action became possible. These preparations would be of three main kinds:-

(a) broadcast instructions designed, not merely to sustain morale, but to prepare people in Zone Z to co-operate in their own relief and in particular to convey to those who had their own transport when to move and in what direction to head;

(b) preparation of reception centres in Zone W and beyond and preliminary planning of the clearance movement; and

(c) marshalling transport and organising teams to conduct the clearance operation.

40. <u>Self-help within the zone</u>. The first lift would make use of vehicles already within Zone Z, mainly no doubt private cars, but not excluding motor and pedal cycles and any commercial vehicles whose drivers could get them on the road without going far on foot to collect them. Broadcast instructions would have given these people a broad indication of the time when they should start and of the areas outside Zone X where they might expect to find arrangements made for their reception. It would be stressed in the broadcast advice how important it would be for no one to leave the zone with less than a full load; people would, however, be leaving the zone for a period of some months and would have to bring some luggage with them. Traffic control would be an important police problem. The movement would, however, be one-way and the broadcast instructions could be used to secure some kind of spread-over to ease the situation at the reception end. It would be important to guard against outgoing vehicles impeding transport entering the zone to conduct the second phase of the clearance operation.

41. Some people who had their own transport might not receive the broadcast instructions either because they had no set or because of electricity failure. These people, if not told by neighbours of the instructions given to those with their own transport, would be in the same position as those who have no transport and who were dependent for their evacuation on being fetched.

42. <u>Preparation of reception centres in the free zone</u>. Population density in parts of the country would already be high as a result of the pre-attack evacuation movement. A further population movement into and through these areas would produce acute difficulties of billeting and accommodation as well as of traffic control. The organisation of a large number of reception centres, preferably conveniently sited for further movement by rail, would have to be undertaken before clearance started; people using their own motor transport should be routed through to areas well beyond the areas in which reception centres were set up.

43. <u>Marshalling of evacuation transport and organisation of teams</u>. It would be unsafe, however, to rely on the self-help movement described in paragraph 40 accounting for more than a quarter to a third of the normal population of the zone; allowance must also be made for the effect of the pre-attack evacuation which might have doubled the population in the zone. Wireless broadcasting would need to be used to the fullest extent to explain to the remainder the plans being made to help them; only thus could they be kept in good heart and be convinced of the necessity to remain in their refuges until their turn came. The clearance operation would necessarily be spread over some time and might be delayed for a period as regards the inner areas; people would need to be forcefully reminded that they should not venture into the open except on a direct summons.

44. The first requirement in planning the operation would be for the zone to be broken down into small areas which could be assigned to clearance teams; the wardens post would be the natural unit for this purpose as it is for the control scheme itself. Each team, under the charge of a clearance officer, would have the task of completely clearing its allotted post area, and the movement would take place from as many areas as possible concurrently. During the waiting period, clearance officers would themselves be briefed, study the areas assigned to them and make detailed arrangements with their allotted transport drivers as soon as these reported. The clearance officer would move in to his assigned area in Zone Z as soon as practicable after authority to start the movement was given and establish himself at the warden's post.

45. Conduct of the Clearance Operation. The clearance officer would supervise the operation, acting in conjunction with the post warden. It would be unsafe to rely on the post warden alone who might well be incapacitated. Occupants of houses, who had not moved out, would have been told to signal by way of a window card or other similar device that they were ready to leave when called for. Transport assigned for the operation would report to the clearance officer and be detailed systematically to cover his allotted area. The best procedure would probably be to concentrate on one street at a time. Wardens and street leaders might assist when transport arrived in their own streets by knocking at the doors of all houses displaying the appropriate sign; the aim should be to ensure that no one vehicle spent more than 30 minutes in the zone collecting its load. Persons leaving their homes would be limited to a single suitcase containing their personal effects. When the clearance officer was satisfied that all who wanted to leave had been able to do so, he and the post warden would withdraw. The question of people who did not wish to leave their homes or billets in Zone Z would be a thorny one. They might include people with a degree of protection comfortably above average and a good store of food and water and their own means of transport. In the nature of the case there could be no enforcement, only persuasion, itself based on public education before the event. Clearance of the area would imply that the public services would not be restored for a considerable time; no one would be able to stay indefinitely.

46. The timing of any clearance operation would be a matter for decision at the time. It could not begin before 48 hours had elapsed, but there are obvious psychological and other reasons why it should not start much later. The conditions as regards the air battle might influence the decision.

IX. OPERATION OF THE CONTROL SCHEME

47. The control scheme described in this memorandum will place new and important obligations on regions, on local authority controls, and on the civil defence services, especially the wardens service. The precise manner in which these obligations would be discharged will have to be determined over a period of time as a result of practical trials and experience. This section accordingly attempts only to sketch in very general terms the tasks to be performed and to outline how they may be carried out.

48. Fixing the Zone boundaries. Regions and the central government would receive a forecast and subsequently a picture of fall-out as it was taking place from the monitoring organisation established, inter alia, to provide the information on which the warning system described in Section III would operate. This would be based on readings provided by a network of some 1,500 Royal Observer Corps reporting posts, and it would provide a broad appreciation of the fall-out situation. It would not be sufficiently detailed to settle the precise zone boundaries, but it would provide what was needed at the highest levels of control in the early stages of fall-out. Each zone boundary on the ground would need to be identified as rapidly as possible in terms of the boundaries of a connected chain of wardens post areas determined by the appropriate controls from among the 19,000 or more wardens posts in the country; identification of the posts forming this chain would be a slower process. The procedure for settling the zone category of wardens posts and the resulting fixing of zone boundaries is likely to be on the lines indicated in the succeeding paragraphs.

49. To avoid wardens being exposed to radioactivity while the fall-out was coming down, they would not normally be expected to take dose rate readings until instructed to do so by the appropriate control after the dose rate had begun to decline. The instruction to start taking readings would be given after receipt of the "Blue" message signifying that fall-out was complete. Readings would not necessarily be called for from all posts in a given local authority area immediately, especially if, by sampling, the control discovered high dose rates which made an early decision on the zone category unnecessary. The control (which would have been informed of the time of burst to which to relate its predicted dose rates at 48 hours and, as the information became available, of the rough location of contours) would probably be able to judge which of its posts were critically placed for purposes of settling zone boundaries and would start by collecting readings from those posts. With this information fairly accurate categorisation of wardens post areas should be possible, subject to any necessary checking by higher levels of control especially as regards the junctions of zone boundaries with adjoining control areas. Posts in Zones X and Y would on completion of this process, be notified of their zone category and of the time at which they should set in motion the appropriate release procedure; Zone Z posts would be told to await further information on the plans for clearing the zone; Zone W would be dealt with as described below.

50. Controlling the movement of the W Zone boundary. The determination of the W Zone and the regulation of its effective boundary would be of most importance in the early stages.

After calling for dose rate readings from its posts, the control would have discretion to release immediately post areas where the reading was already below 0.3 r.p.h. provided the post was not flanked by other posts with substantially higher readings. Before any post which abutted on the area of another control was released, consultation with that other control would be essential as a precaution against higher readings just over the boundary and to find out whether or not warning notices were required to be exhibited at the boundary.

51. When a W Zone post was released by its control, the wardens would have two main duties:-

(a) if informed by control that their post had an area not yet released on one flank, to put up "DANGER - FALL-OUT" notices at the boundary of their post area on all roads leading into that area; and

(b) to cancel the fall-out warning for their area and remove any notices which had served their purpose.

52. The release of the rest of Zone W would be based on a system of standard release times - at 0600, 1200, 1800, and 2359 hours (four hourly intervals might be possible). As soon as the initial release of fringe posts had been put in hand, control would calculate for each of its post areas the time at which it expected the dose rate to drop to 0.3 r.p.h. On the basis of this calculation proposed release lines at the standard times would be passed up through the various levels of control for confirmation. Each level, e.g., County or Region, would rectify any inconsistencies between adjoining areas. Provisional release times would be notified by controls to all posts in Zone W as soon as the local proposals had been checked and any necessary modifications made. It would then remain only for posts to take a reading one hour before each standard release time to enable the control to check that the radioactivity was decaying as expected. By this means the outer boundary of the fall-out area would move in systematic fashion across Zone W and warning notices would be exhibited or removed at each stage as appropriate.

53. Controlling the clearance of Zone Z. The planning and conduct of the clearance operation described in Section VIII would involve many agencies. While the local authorities and the wardens service within Zone Z would have a part to play, it seems impracticable for the operation to be controlled by them; this would have to be done from outside the zone. The marshalling and direction of the transport movement on the scale required would be an immense task. There will be evident scope for assistance by the Army in such an operation and considerable responsibilities must, in the nature of the case, fall to the police. The broad scope and timing of any clearance operation would rest with the Regional Commissioner but it may prove desirable to entrust detailed planning and execution of the movement to a specific service. This will be further examined.

54. Role of the Wardens Service. From the references throughout this memorandum to the duties of wardens, it will be evident that a whole range of new duties would be entrusted to them under the scheme. The effect of these new obligations on existing doctrine as regards the functions of the Wardens Service will be dealt with in a subsequent memorandum.

55. <u>Role of the Police.</u> It is also clear that, in addition to the responsibilities falling to local authority controls and the Wardens Service under the scheme, the police will have an important part to play. Co-operation between wardens and police in local post areas would be essential and the police system of communications would be a valuable adjunct for the working of the whole scheme. As a general rule it may be taken that messages relating to the operation of the control scheme passing through the civil defence chain would be repeated through the police network. The requirements of a public control scheme such as is described in this memorandum underline the importance of preserving the existing close association between the police and the Wardens Service.

Home Office, S.W.1.
Scottish Office, Edinburgh, 1.

TOP SECRET

Minister of Defence

("Strath Report")

PRIME MINISTER

KEY- mis- reported in "news" propag. in 2002!

The Defence Implications of Fall-Out from a Hydrogen Bomb

(D.(55) 17 and 18)

D.(55) 17 is the report of the group of officials appointed at the end of last year to assess the defence implications of fall-out from a hydrogen bomb. Its broad conclusion is that, although a determined hydrogen bomb attack against this country would cause human and material destruction on an appalling scale, it would be possible to contain its effects and enable the nation to survive if adequate preparations had been made in advance.

2. Many new problems are posed by the hydrogen bomb. The report does no more than outline possible solutions: much more work must be done before it can be firmly decided how far these are practicable and financially acceptable. The study was based on the best scientific information available in this country, which is closely in line with information subsequently released by the United States authorities. But our scientists are still handicapped by lack of information which the United States authorities alone can supply from the work which they have already done. Though they cannot under their legislation disclose information about the actual performance of their weapons or about methods of manufacture, it seems reasonable that the Western Alliance should pool information on methods of defence against hydrogen bomb attack and one would hope that much useful knowledge and experience on this aspect of the problem could be made available without prejudice to United States security requirements. You may wish to mention this point to Admiral Strauss, at your talk with him on Friday afternoon.

3. The group of officials was primarily concerned with the problems of home defence and in particular with the responsibilities of the civil authorities. I understand that the studies on the active defence side mentioned in Section 13 of the Report have already been initiated. But the Defence Committee may like to confirm from the Chiefs of Staff that the Services are making a corresponding study of the

TOP SECRET

13

MINISTRY OF DEFENCE, S.W.1.

PRIME MINISTER

I am glad to have your general approval of my proposals for studying the effect of "fall-out" on our war plans.

2. I am appointing the following to carry out the preliminary study described in paragraph (3) of my minute:-

Mr. W. Strath	- Cabinet Office
General Brownjohn	- Representing the Chiefs of Staff
Sir Richard Powell	- Deputy Secretary, Ministry of Defence
Sir Frederick Brundrett	- Scientific Adviser to the Ministry of Defence
General Kirkman) Mr. P. Allen)	- Home Office

This group will be under the chairmanship of Mr. Strath, who is working in the Cabinet Office under the personal direction of Sir Norman Brook on the inter-departmental aspects of war plans. On the choice of the other members of the group I have had Sir Norman Brook's advice.

Arrangements will be made to enable this group to obtain advice, as required, from the Chairman of the Joint Intelligence Committee, the Economic Adviser to the Treasury and the atomic scientists in the Atomic Energy Authority.

TOP SECRET

The military consequences of "fall-out" will be studied by the Chiefs of Staff themselves; but General Brownjohn will provide the link between them and Mr. Strath's group.

3. As decided this afternoon before the Cabinet, I am arranging to send my paper (C(54)389) to members of the Cabinet. It will go with your paper on Tube Alloys and to the same limited circulation.

13th December, 1954

"Keep me informed please.
W.S.C.
14/12."

14/12.

TOP SECRET

P.S. TO MINISTER OF DEFENCE

FALL - OUT

Sir Norman Brook yesterday sent to the Minister of Defence a draft memorandum on "fall-out".

Sir Frederick Brundrett has called my attention to an error in the Annex which requires correction. The penultimate sentence of the paragraph at the top of page 5 of the Annex should read as follows: "A thickness of 12 inches of earth would reduce the radiation dosage rate by a factor of about 15". I should be grateful if you would make the necessary correction in the paper which your Minister has.

(W. STRATH)

30th November 1954

E.R.

TOP SECRET

FALL-OUT

Draft Memorandum by the Minister of Defence

I attach a note on the effects of the explosion of a thermo-nuclear bomb. Its main purpose is to describe the conditions created by fall-out - the radio-active contamination which is caused when a bomb bursts at or near ground level. The effects of other forms of energy released by a thermo-nuclear explosion - blast and heat - are outlined briefly.

2. This analysis is founded on the latest scientific information we have. It accords with all that we have been able to find out about the effects of the experiments by the United States in the Pacific and elsewhere. It is also supported by a similar analysis carried out by the Canadians. We would naturally like to have consultation with the United States in order to confirm that the conclusions reached by our scientists are compatible with those to which American scientists have come. From the varied contacts which have taken place with the Americans, we have no reasons to suppose that they would dissent on any point of substance from the analysis here given. But we cannot be certain of this until our formal request to the Department of Defence for co-operation and consultation in this field has been submitted to Congress for approval as required by the 1954 Atomic Energy Act. I understand that the United States Administration hope to lay the proposed Agreement before Congress in January. In such event the consequent constitutional processes should be completed in time to permit of joint consultation with us early next spring.

3. This means that the United States Authorities will continue to be debarred from entering into the discussions, which they as well as we agree are necessary, until after the defence estimates are presented to Parliament for 1955/56. Regrettable as this is, we should, I think, consider whether there are not certain aspects on which an approach should be made in the meantime. We need, for example, to discuss with them the revised strategic

/concept

E.R.

concept of the Chiefs of Staff and the implications which this has for Allied defence policy. Even more urgent is the need to consult with them on the political problems with which they as well as we are faced in presenting to the public the changes which the advent of the hydrogen bomb imposes on our respective preparations for defence.

4. There are indications that the United States Government are now considering the political implications of the hydrogen bomb for their home front. But we cannot be sure that they will consult us before making any public announcement about its impact on their defence plans, and, if they should announce their policy without prior consultation with us, we must be able to show that we are not unprepared for these problems in our new defence policy. Moreover, by initiating discussions with the Americans on the aspects which I have suggested, we should avoid giving the impression that the purpose of our approach is to obtain information about atomic energy, which they consider themselves unable to give us without the approval of Congress.

5. Valuable though United States confirmation of our conclusions about fall-out would be, our scientists are confident that the margin of possible error in the attached analysis is not wide enough to invalidate its substance. Moreover, the significance of fall-out for our defence planning would not be materially affected even if the consequences were later found to be somewhat less bleak than they appear now. There are no grounds, therefore, for deferring the necessary re-orientation of our planning until we can check our own conclusions with the Americans.

6. It is, I think, evident that this new information must have a revolutionary effect over a wide range of our war plans, both military and civil. Thought is already being given to its implications by the limited circle of Ministers and officials to whom this scientific appreciation is known. But we cannot ensure that all our preparations will be properly adjusted to allow for this new factor without widening the limit within which knowledge

/of the

E.R.

of the new implications has so far been confined. Unless this is arranged, much of our planning is bound to get out of gear.

7. If this is done, however, we must accept some risk that people may come to know quite soon that the Government are planning on this new hypothesis. Admittedly, almost all the conclusions in the attached note could be reached by diagnosis of material which has been published. But much of the present indifference of the public would vanish if they found that the Government had adopted this basis for their defence plans.

8. I therefore propose that we should now consider:-

(a) The extent to which it is desirable to issue guidance on the implications of fall-out to Departments concerned with defence preparations.

(b) The manner in which the implications of fall-out for our defence policy should be presented to the public, bearing in mind that the facts of this subject are in large measure already available to them and that the radical changes in Government plans require to take account of fall-out cannot long be concealed from the public once they are applied to our defence preparations.

(c) The form and timing of an approach to the United States Government on problems raised in this paper. The emphasis on the initial discussions should, I suggest, be on the common political problems which are raised for the Americans as well as ourselves by the development of thermo-nuclear weapons, and on the importance of harmonising the presentation to the public of the changes which we must each make in our defence policy. It would also be valuable to exchange views with the Americans, initially perhaps on the Chiefs of Staff level, on the implications of the latest developments for the strategic policy of the Western alliance.

NOVEMBER 1954

T 47/57

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UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT No. T 47/57

BB005

OPERATION BUFFALO

Target Response Tests
(Co-ordinator : E. R. Drake Seager)

The Effect of Earth Covers on the Resistance
of Trench Shelter Roofs

A. J. Wood

UKR2.67

A.W.R.E.,
Aldermaston, Berks.

[redacted]

August, 1957

UNCLASSIFIED

[redacted]

United Kingdom Atomic Energy Authority

ATOMIC WEAPONS RESEARCH ESTABLISHMENT

REPORT NO. T47/57

OPERATION BUFFALO

The Effect of Earth Covers on the Resistance of Trench Shelter Roofs

A. J. Wood

Summary

This report describes the effect of an atomic weapon of about 20 kilotons total energy yield on full-size and model trench shelter roof panels with varying amounts of earth cover. Static tests on both scales were also carried out, and details of all results obtained are given.

Received on 22nd July, 1957

1. Introduction

To obtain information on the effect of earth cover on the resistance to blast of trench shelter roof slabs a series of targets was exposed to Round 1 of Operation Buffalo, which had a total energy yield of about 20 kilotons. These targets were both full-scale and model scale. The model targets were 1/10th full-size, and were included to provide information on the effects of a Megaton weapon.

The slabs were designed by the Ministry of Works [Refs. 1 and 2], the overall dimensions of the full-scale panels being 21 ft × 8 ft × 6 in., and of the 1/10th scale panels 25 in. × 9.4 in. × 0.6 in. The discrepancy between the full-size and model dimensions was caused by differences in the widths of the bearing surfaces; for the full-size slabs this surface was 6 in. all round, giving a clear span of 20 ft × 7 ft, whereas the model slabs were supported on bearing surfaces only 0.5 in. wide, giving a free span of 24 in. × 8.4 in. The corners of the slabs were held down (with reinforcing rods and concrete on the full-size slabs, and special steel clamps on the model slabs) for a length equal to 1/10th of the free span in each direction.

Eight full-size slabs were to be cast, six to be placed in the field, the remainder to be tested statically. Of the six in the field three were at ground level and the other three were buried to give 5 ft of earth cover. Forty-eight models were cast, 36 of which were exposed in the field, 9 models being buried 12 in. below ground level, 9 buried 6 in. deep, 9 buried 3 in. deep and 9 placed level with the surface of the ground.

2. Object of the Investigation

2.1 Full-Size Slabs

The main purpose of this test was to study the effect of earth cover upon the resistance of a reinforced concrete slab to blast loading from a kiloton weapon, and to determine whether static tests could be used to predict performance under blast loading.

7. Comment on Results

7.1 Effect of Earth Cover on Full-Size Slabs

The effect of the earth cover on the full-scale slabs can be seen in Table 1. It will be noticed that whereas a panel at about 22 p.s.i. with no cover was destroyed, that at 27 p.s.i. with 5 ft of earth cover, whilst being heavily damaged, was not destroyed. From this example it would seem that the earth cover had a considerable effect. However, the panel at $14\frac{1}{2}$ p.s.i. with no cover had a residual central deflection only very slightly greater than that with earth cover at 10 p.s.i. and less than half the deflection of the panel with cover at 18 p.s.i. These points would indicate that the cover had a greater effect at the higher pressures. It will be seen from Table 1 that the mean compressive strength of the statically tested panel was only about 2000 p.s.i. as compared with a value for the field tested panels of 3000 p.s.i. In information not yet published it has been shown that an increase of strength of this order on a 12 in. square unreinforced panel 1 in. thick gives an increase of static strength of about $1\frac{1}{2}$ p.s.i. It is considered that the increase in strength on a full-scale trench shelter roof panel would be of the same order.

7.2 Effect of Earth Cover on Model Panels

Table 2 shows that all panels were destroyed at pressures greater than 22 p.s.i. At 18 p.s.i. the only panels to survive were those with 6 in. of earth cover, and these were very near to collapse. Those panels with 3 in. of cover exposed at 14.5 p.s.i. survived, as did all panels exposed to pressures equal to or less than 13 p.s.i.

The damage sustained by these model slabs is comparable with that which full-scale slabs should experience at the same pressure level from a weapon in the kiloton range. The abnormal shape of the blast wave at the nearer distances will have a small but not outstanding effect.

The figures given for the final central deflection are not necessarily a reliable guide to the maximum deflection [Ref. 5], but are included as the only real indication that the panels suffered any damage at all since only four of the surviving panels were visibily cracked, and as can be seen from the photographs in Figures 9-22 the cracking even in these cases was very light.

8. Conclusions

The test showed that the earth cover on the full-size slabs did in fact have the effect of reducing damage, while on the model scale, although the effect was not so marked, it was apparent. The range of damage sustained was, on the whole, satisfactory for both the model and full-scale, which, since the ranges for both types were predicted from model static and blast tests, indicates that this is an acceptable method for predicting performance under blast loading.

References

1. Ministry of Works Drawing No. Q/1036B.

2. Ministry of Works Drawing No. Q/546B.

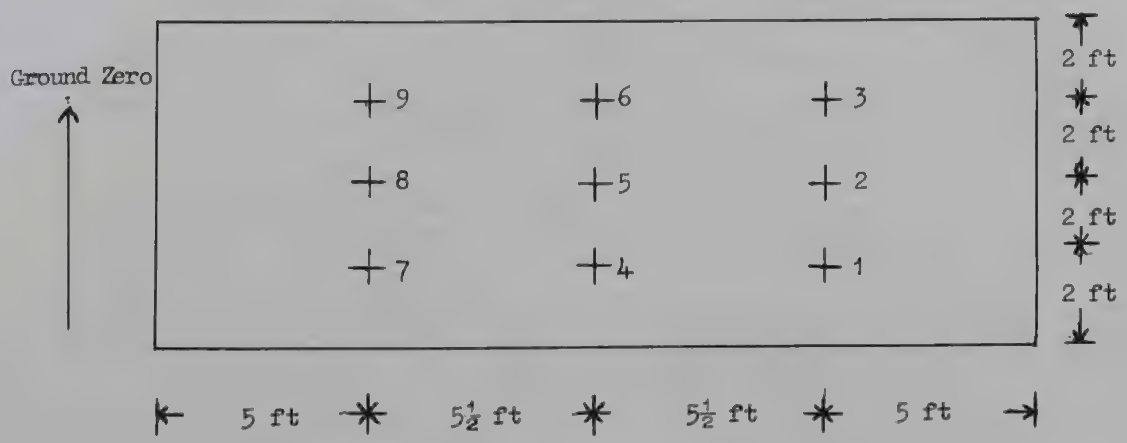
3. A. J. Wood: "The Design of Concrete Mixes Using Limestone Aggregates Available at Maralinga". AWRE Report No. T35/57.

4. T. P. O'Brien and Pepita Pirrie: "Investigation of the Static Strength and Resistance to Air Blast of 1/10th Scale Trench Shelter Roof Slabs". AWRE Report No. E5/57.

5. T. P. O'Brien and Pepita Pirrie: "Investigation of the Effect of Blast Loading on the Damage Sustained by 1/10th Scale Reinforced Concrete Panels". AWRE Report No. E8/56.

TABLE 1

Details of Damage to Full-Size Panels



Plans of Slab: Positions at which Deflections were recorded Shown: +

Panel No.	Maximum Pressure, p.s.i.	Deflection (in.) at Position									Control Cube Strength, p.s.i.	Modulus of Rupture, p.s.i.
		1	2	3	4	5	6	7	8	9		
Panels with No Cover												
2A/A/4	21.6					Destroyed					3230	430
2A/A/6	14.5	0.4	0.7	0.4	0.5	0.9	0.5	0.3	0.6	0.4	3510	449
2A/A/8	10.3	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	2750	347
Panels with 5 ft Earth Cover												
2A/A/2	27.0	0.7	3.5	1.7	2.0	4.1	1.9	1.9	3.4	1.7	3340	346
2A/A/5	17.9	0.8	1.3	0.5	1.0	2.1	0.7	0.7	1.6	0.6	2969	360
2A/A/7	12.0	0.3	0.4	-0.1	0.4	0.8	0.2	0.4	0.7	0.3	2234	320

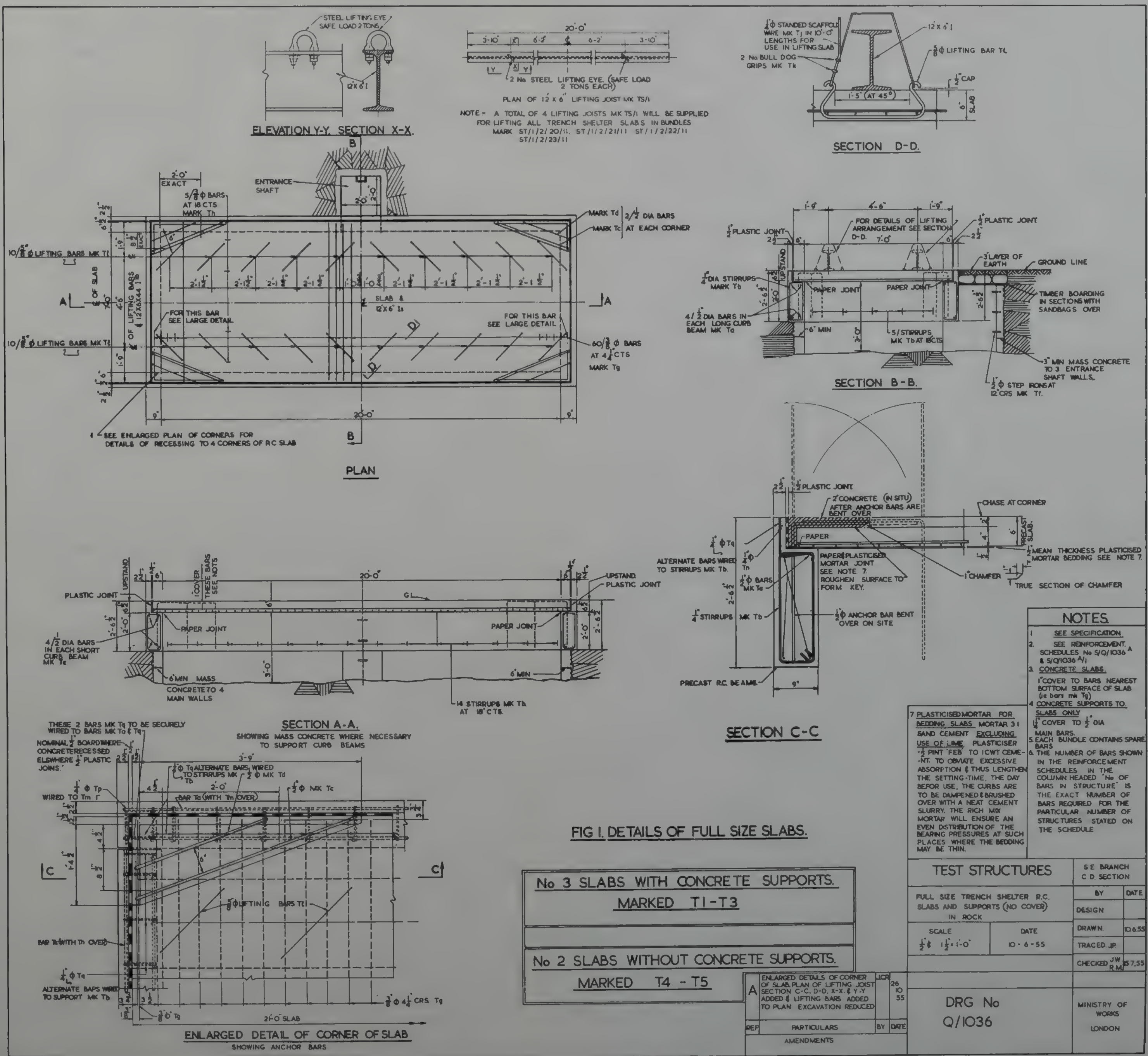
Panel No. 2A/A/3 was tested statically: Max. load = 14.61 p.s.i.
Central defl. at max. load = 1.85 in.
Control cube strength = 2140 p.s.i.
Modulus of rupture = 257 p.s.i.

TABLE 2

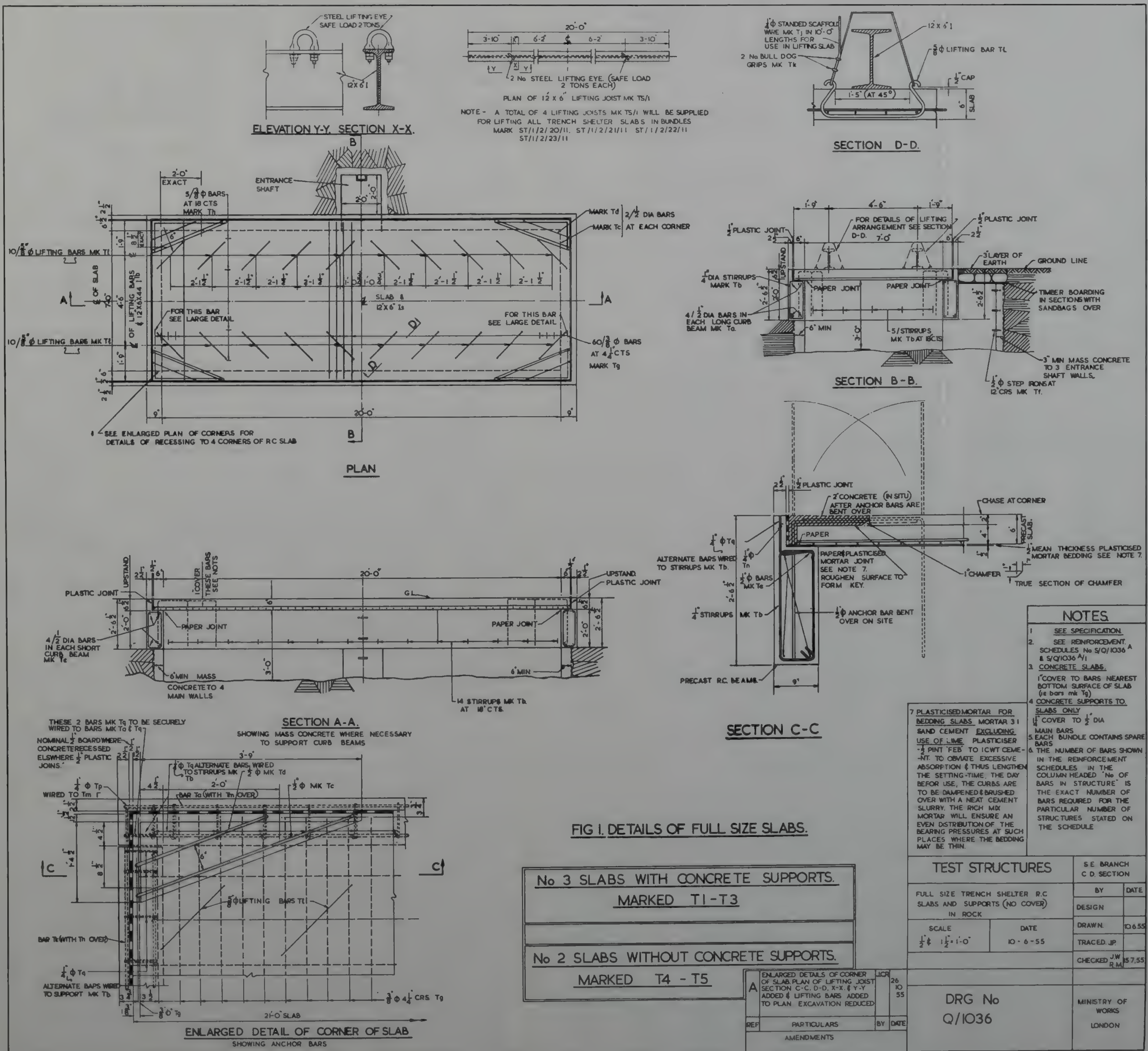
Details of Damage to Model Panels

Panel No.	Maximum Pressure, p.s.i.	Final Central Deflection, in.	Control Panel Characteristics			
			Cube Strength, p.s.i.	Modulus of Rupture, p.s.i.	Max. Static Pressure, p.s.i.	Deflection at Max. Load in.
Panels with No Cover						
2B/B/2	21.6	Destroyed	3330	651	8.56	0.060
2B/A/2	17.9	Destroyed	3440	609	9.55	0.043
2B/B/4		Destroyed	3330	651	8.56	0.060
2B/D/1		0.076	3750	724	8.30	0.039
2B/C/1	13.2	0.062	3420	703	10.37	0.049
2B/D/2		0.057	3750	724	8.30	0.039
2B/D/5	10.3	0.057	3750	724	8.30	0.039
2B/E/5		0.056	3290	682	9.00	0.083
2B/F/1	8.0	0.048	3120	609	10.47	0.084
Panels with 3 in. Earth Cover						
2B/C/6	23.8	Destroyed	3420	703	10.37	0.049
2B/C/4	17.9	Destroyed	3420	703	10.37	0.049
2B/G/4		Destroyed	3230	661	11.14	0.079
2B/E/2		0.069	3290	682	9.00	0.083
2B/F/6	14.5	0.054	3120	609	10.47	0.084
2B/A/5		0.094	3440	609	9.55	0.043
2B/D/4	11.1	0.057	3750	724	8.30	0.039
2B/G/2		0.062	3230	661	11.14	0.079
2B/H/4	9.0	0.041	3490	598	10.38	0.122
Panels with 6 in. Earth Cover						
2B/E/1	27.0	Destroyed	3290	682	9.00	0.083
2B/D/6	21.6	Destroyed	3750	724	8.30	0.039
2B/C/5		Destroyed	3420	703	10.37	0.049
2B/C/2		0.127*	3420	703	10.37	0.049
2B/G/1	17.9	Destroyed	3230	661	11.14	0.079
2B/B/1		0.184*	3330	651	8.56	0.060
2B/A/6	13.2	0.042	3440	609	9.55	0.043
2B/F/4		0.053*	3120	609	10.47	0.084
2B/B/6	10.3	0.040	3330	651	8.56	0.060
Panels with 12 in. Earth Cover						
2B/A/4	33.5	Destroyed	3440	609	9.55	0.043
2B/G/5	27.0	Destroyed	3230	661	11.14	0.079
2B/E/4		Destroyed	3290	682	9.00	0.083
2B/B/5		Destroyed	3330	651	8.56	0.060
2B/E/6	21.6	Destroyed	3290	682	9.00	0.083
2B/F/5		Destroyed	3120	609	10.47	0.084
2B/A/1	17.9	Destroyed	3440	609	9.55	0.043
2B/F/2		Destroyed	3120	609	10.47	0.084
2B/G/6	12.0	0.068*	3230	661	11.14	0.079

*Visible cracking



ELEVATION Y-Y. SECTION X-X.
STEEL LIFTING EYE SAFE LOAD 2 TONS
PLAN OF 12 x 6" LIFTING JOIST MK TS/1
2 No STEEL LIFTING EYE (SAFE LOAD 2 TONS EACH)
NOTE - A TOTAL OF 4 LIFTING JOISTS MK TS/1 WILL BE SUPPLIED FOR LIFTING ALL TRENCH SHELTER SLABS IN BUNDLES MARK ST/1/2/20/11. ST/1/2/21/11 ST/1/2/22/11 ST/1/2/23/11
SECTION D-D.
PLAN
SEE ENLARGED PLAN OF CORNERS FOR DETAILS OF RECESSING TO 4 CORNERS OF R.C SLAB
SECTION B-B.
SECTION A-A.
SHOWING MASS CONCRETE WHERE NECESSARY TO SUPPORT CURB BEAMS
SECTION C-C
ENLARGED DETAIL OF CORNER OF SLAB
SHOWING ANCHOR BARS
FIG I. DETAILS OF FULL SIZE SLABS.
No 3 SLABS WITH CONCRETE SUPPORTS.
MARKED T1-T3
No 2 SLABS WITHOUT CONCRETE SUPPORTS.
MARKED T4 - T5
NOTES.
1 SEE SPECIFICATION.
2. SEE REINFORCEMENT SCHEDULES No S/Q/1036 A & S/Q/1036 A/1
3. CONCRETE SLABS. 1" COVER TO BARS NEAREST BOTTOM SURFACE OF SLAB (ie bars mk Tg)
4 CONCRETE SUPPORTS TO SLABS ONLY. 1 1/2" COVER TO 1/2" DIA MAIN BARS.
5 EACH BUNDLE CONTAINS SPARE BARS
6. THE NUMBER OF BARS SHOWN IN THE REINFORCEMENT SCHEDULES IN THE COLUMN HEADED "No OF BARS IN STRUCTURE" IS THE EXACT NUMBER OF BARS REQUIRED FOR THE PARTICULAR NUMBER OF STRUCTURES STATED ON THE SCHEDULE
7 PLASTICISED MORTAR FOR BEDDING SLABS. MORTAR 3:1 SAND CEMENT EXCLUDING USE OF LIME. PLASTICISER -1/4 PINT "FEB" TO 1CWT CEMENT. TO OBVIATE EXCESSIVE ABSORPTION & THUS LENGTHEN THE SETTING-TIME, THE DAY BEFOR USE, THE CURBS ARE TO BE DAMPENED & BRUSHED OVER WITH A NEAT CEMENT SLURRY. THE RICH MIX MORTAR WILL ENSURE AN EVEN DISTRIBUTION OF THE BEARING PRESSURES AT SUCH PLACES WHERE THE BEDDING MAY BE THIN.
TEST STRUCTURES
FULL SIZE TRENCH SHELTER R.C. SLABS AND SUPPORTS (NO COVER) IN ROCK
SCALE 1/2" & 1 1/2" = 1'-0"
DATE 10-6-55
S.E. BRANCH C.D. SECTION
DESIGN
DRAWN 10.6.55
TRACED JP
CHECKED 15.7.55
A ENLARGED DETAILS OF CORNER OF SLAB, PLAN OF LIFTING JOIST SECTION C-C, D-D, X-X, & Y-Y ADDED & LIFTING BARS ADDED TO PLAN. EXCAVATION REDUCED 26 10 55
REF PARTICULARS BY DATE
AMENDMENTS
DRG No Q/1036
MINISTRY OF WORKS LONDON


ELEVATION Y-Y. SECTION X-X.
STEEL LIFTING EYE SAFE LOAD 2 TONS
PLAN OF 12 X 6 LIFTING JOIST MK TS/1
2 No STEEL LIFTING EYE (SAFE LOAD 2 TONS EACH)
NOTE - A TOTAL OF 4 LIFTING JOISTS MK TS/1 WILL BE SUPPLIED FOR LIFTING ALL TRENCH SHELTER SLABS IN BUNDLES MARK ST/1/2/20/11, ST/1/2/21/11 ST/1/2/22/11 ST/1/2/23/11
SECTION D-D.
2 No BULL DOG GRIPS MK Tk
LIFTING BAR TL
PLAN
ENTRANCE SHAFT
MARK Td 2/½ DIA BARS
MARK Tc AT EACH CORNER
FOR THIS BAR SEE LARGE DETAIL
SEE ENLARGED PLAN OF CORNERS FOR DETAILS OF RECESSING TO 4 CORNERS OF RC SLAB
SECTION B-B.
FOR DETAILS OF LIFTING ARRANGEMENT SEE SECTION D-D.
PLASTIC JOINT
GROUND LINE
TIMBER BOARDING IN SECTIONS WITH SANDBAGS OVER
PAPER JOINT
3" MIN MASS CONCRETE TO 3 ENTRANCE SHAFT WALLS.
SECTION C-C
CHASE AT CORNER
MEAN THICKNESS PLASTICISED MORTAR BEDDING SEE NOTE 7.
TRUE SECTION OF CHAMFER
PRECAST RC BEAMS
ANCHOR BAR BENT OVER ON SITE
SECTION A-A.
SHOWING MASS CONCRETE WHERE NECESSARY TO SUPPORT CURB BEAMS
UPSTAND
PLASTIC JOINT
6" MIN MASS CONCRETE TO 4 MAIN WALLS
14 STIRRUPS MK Tb AT 18" CTS.
ENLARGED DETAIL OF CORNER OF SLAB
SHOWING ANCHOR BARS
FIG I. DETAILS OF FULL SIZE SLABS.
No 3 SLABS WITH CONCRETE SUPPORTS.
MARKED T1-T3
No 2 SLABS WITHOUT CONCRETE SUPPORTS.
MARKED T4 - T5
NOTES
1 SEE SPECIFICATION.
2 SEE REINFORCEMENT SCHEDULES No S/Q/1036 A & S/Q/1036 A/1
3 CONCRETE SLABS. 1" COVER TO BARS NEAREST BOTTOM SURFACE OF SLAB (ie bars mk Tg)
4 CONCRETE SUPPORTS TO SLABS ONLY 1½" COVER TO ½" DIA MAIN BARS
5 EACH BUNDLE CONTAINS SPARE BARS
6 THE NUMBER OF BARS SHOWN IN THE REINFORCEMENT SCHEDULES IN THE COLUMN HEADED "No OF BARS IN STRUCTURE" IS THE EXACT NUMBER OF BARS REQUIRED FOR THE PARTICULAR NUMBER OF STRUCTURES STATED ON THE SCHEDULE
7 PLASTICISED MORTAR FOR BEDDING SLABS. MORTAR 3:1 SAND CEMENT EXCLUDING USE OF LIME. PLASTICISER ½ PINT "FEB" TO 1CWT CEMENT. TO OBVIATE EXCESSIVE ABSORPTION & THUS LENGTHEN THE SETTING-TIME, THE DAY BEFORE USE, THE CURBS ARE TO BE DAMPENED & BRUSHED OVER WITH A NEAT CEMENT SLURRY. THE RICH MIX MORTAR WILL ENSURE AN EVEN DISTRIBUTION OF THE BEARING PRESSURES AT SUCH PLACES WHERE THE BEDDING MAY BE THIN.
TEST STRUCTURES
S.E. BRANCH C.D. SECTION
FULL SIZE TRENCH SHELTER R.C SLABS AND SUPPORTS (NO COVER) IN ROCK
SCALE ½" & 1½" = 1'-0"
DATE 10-6-55
DESIGN
DRAWN 10.6.55
TRACED JP
CHECKED JW R.M. 15.7.55
A ENLARGED DETAILS OF CORNER OF SLAB PLAN OF LIFTING JOIST SECTION C-C, D-D, X-X, & Y-Y ADDED & LIFTING BARS ADDED TO PLAN. EXCAVATION REDUCED LCR 26 10 55
REF PARTICULARS BY DATE
AMENDMENTS
DRG No Q/1036
MINISTRY OF WORKS LONDON

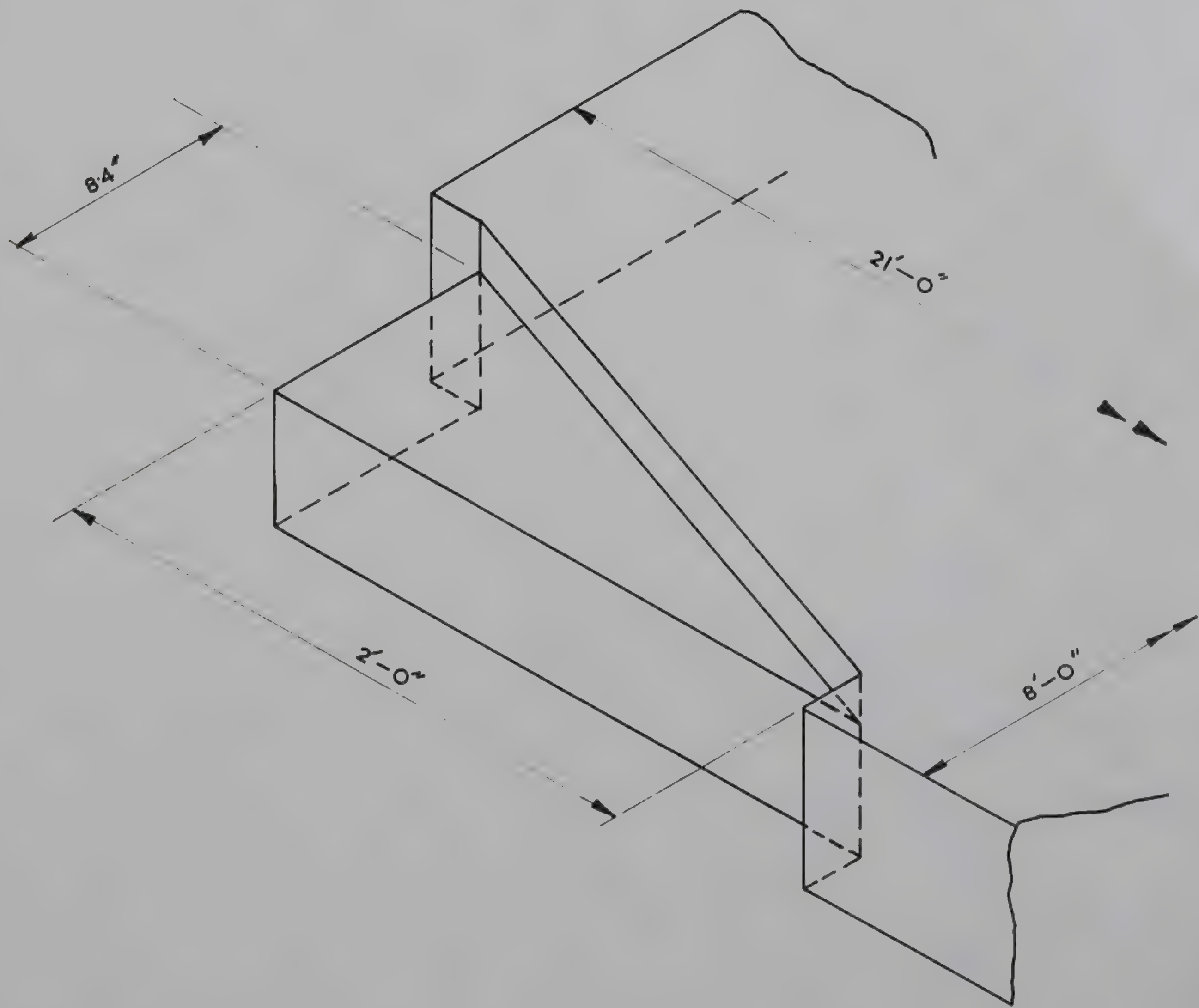


FIG. 2. CORNER DETAIL FULL SIZE SLAB.

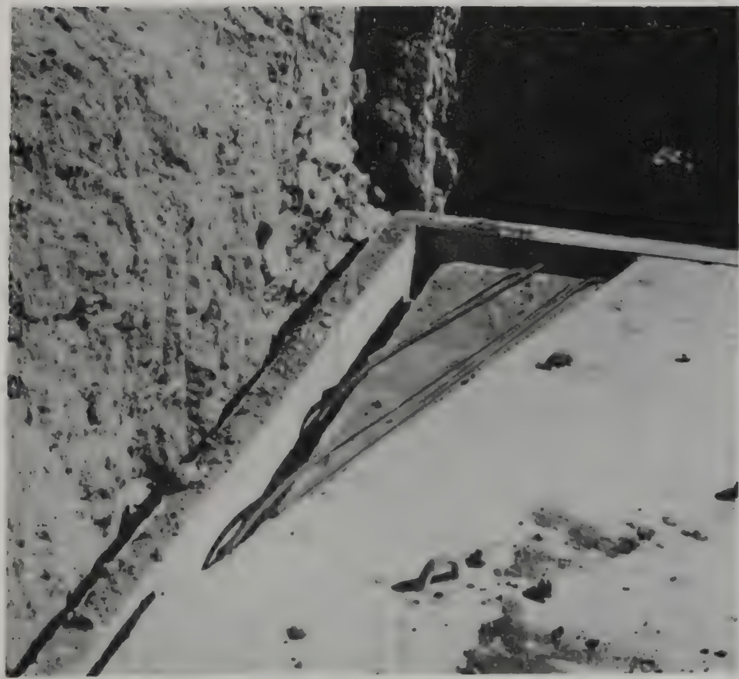


FIG. 3. DETAIL OF CORNER OF FULL SIZE SLAB SHOWING ANCHORING BARS BENT IN POSITION.

FIG. 4. COMPLETED CORNER FULL SIZE PANEL

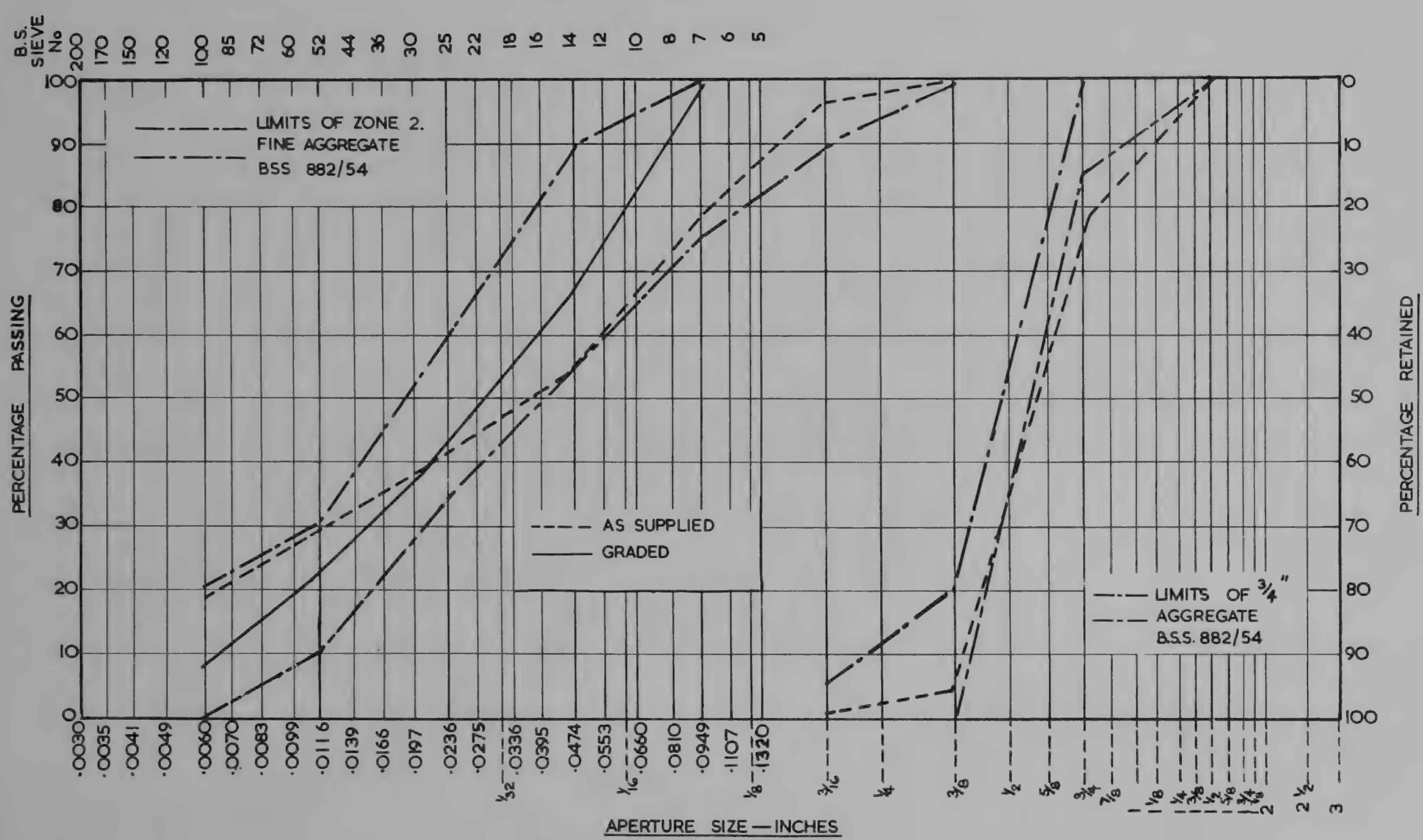


FIG. 5. GRADING OF AGGREGATE.

FIG.6. DIAGRAMS SHOWING POSITIONS OF MIXES IN PANELS. FIGURES UNDERLINED SHOW COMPRESSIVE STRENGTHS AS OBTAINED FROM CONTROL CUBES.

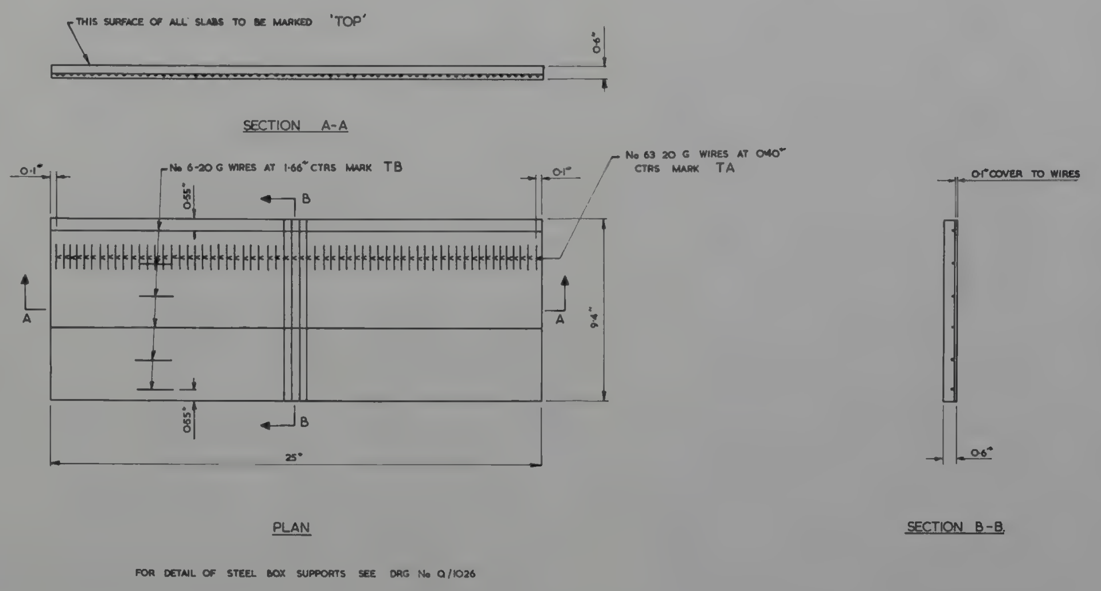
NOTES RE MATERIALS

AGGREGATES.
FINE AGGREGATES SHALL COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 882 THE MAXIMUM SIZE OF AGGREGATE SHALL BE THAT PASSING A 1/16 BRITISH STANDARD SIEVE.

CEMENT.
THE CEMENT SHALL BE PORTLAND CEMENT AND SHALL COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 12.

REINFORCEMENT.
THE REINFORCEMENT SHALL BE MILD STEEL TO COMPLY WITH THE REQUIREMENTS OF BRITISH STANDARD 785. THIS MAY BE OBTAINED BY ANNEALING HIGH TENSILE WIRE PROVIDED THAT THE ULTIMATE STRESS AND ELONGATION IS AS DEFINED IN APPENDIX 'A' OF BRITISH STANDARD 785 FOR MILD STEEL.

REINFORCED CONCRETE.
CONCRETE MIX.
THE CONCRETE IS REQUIRED TO HAVE A MINIMUM COMPRESSIVE STRENGTH AT 28 DAYS OF 3000 LB/SQ.INCH.



SCHEDULE OF WIRE REINFORCEMENT FOR TOTAL No. OF 39 SLABS			
WIRE MARK	S.W.G. No.	TOTAL No.	WIRE LENGTH (INS.)
TA	20	2457	25·0
TB	20	234	9·4

NOTES.

REINFORCING WIRES TO BE CUT OFF FLUSH WITH EDGES OF CONCRETE SLAB

SEE REINFORCEMENT SCHEDULE ON THIS DRG. FOR TOTAL WIRES TO SLABS MARK M.T.1.- M.T. 39. INCLUSIVE

SEE "NOTES" MATERIALS ON THIS DRAWING

No. 39. OFF MARKS MT. 1.–MT. 39.

FIG 7 DETAILS OF $\frac{1}{10}^{TH.}$ SCALE SLABS.

REF.	PARTICULARS	BY	DATE
'A'	No. & LENGTH OF WIRES INCREASED	V.A.N.	18/7/55

AMENDMENTS.

TEST STRUCTURES	S.E. BRANCH. C.D. SECTION.		
MODEL R.C. TRENCH. SHELTER SLABS		BY	DATE
	DESIGN		
	DRAWN	A.C.	
SCALE 3" TO 1 FOOT / DATE	TRACED	E.J.H.	15/4/57
JOB No.	CHECK'D	M.J.	26/4/55
IDENT. No.	STRUCT. FILE No.		
DRG. No. Q/546 B	MINISTRY OF WORKS LONDON		

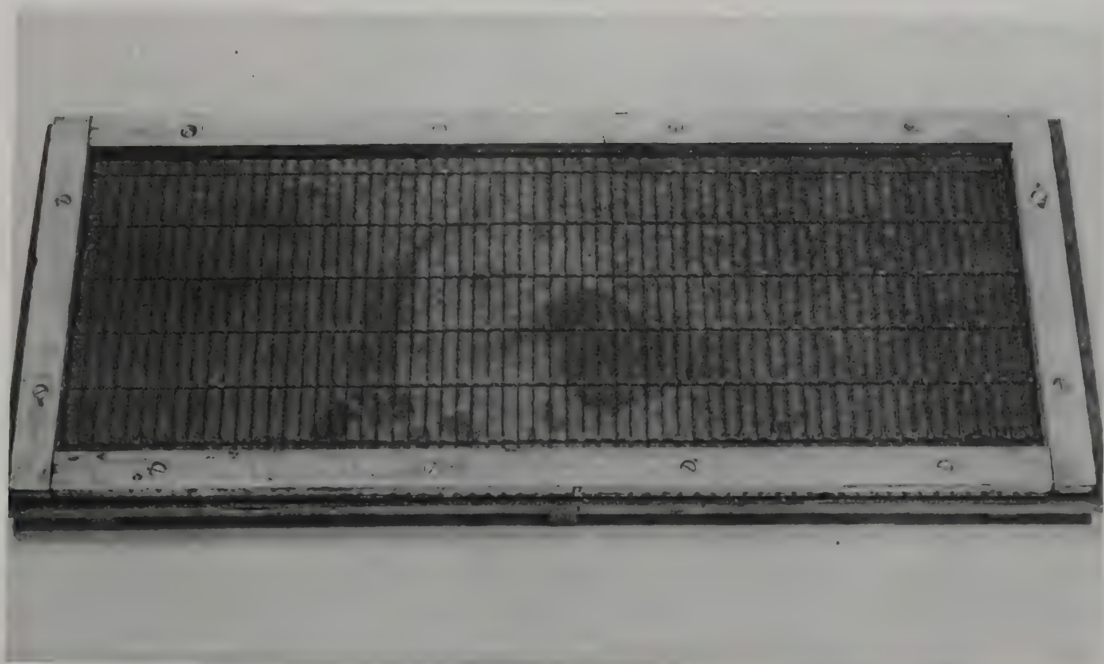


FIG. 8. $\frac{1}{10}$ SCALE MOULD READY FOR CASTING

FIG. 9. PANEL IN SURFACE IN POSITION BEFORE ENTRANCE SHAFT SEALED.

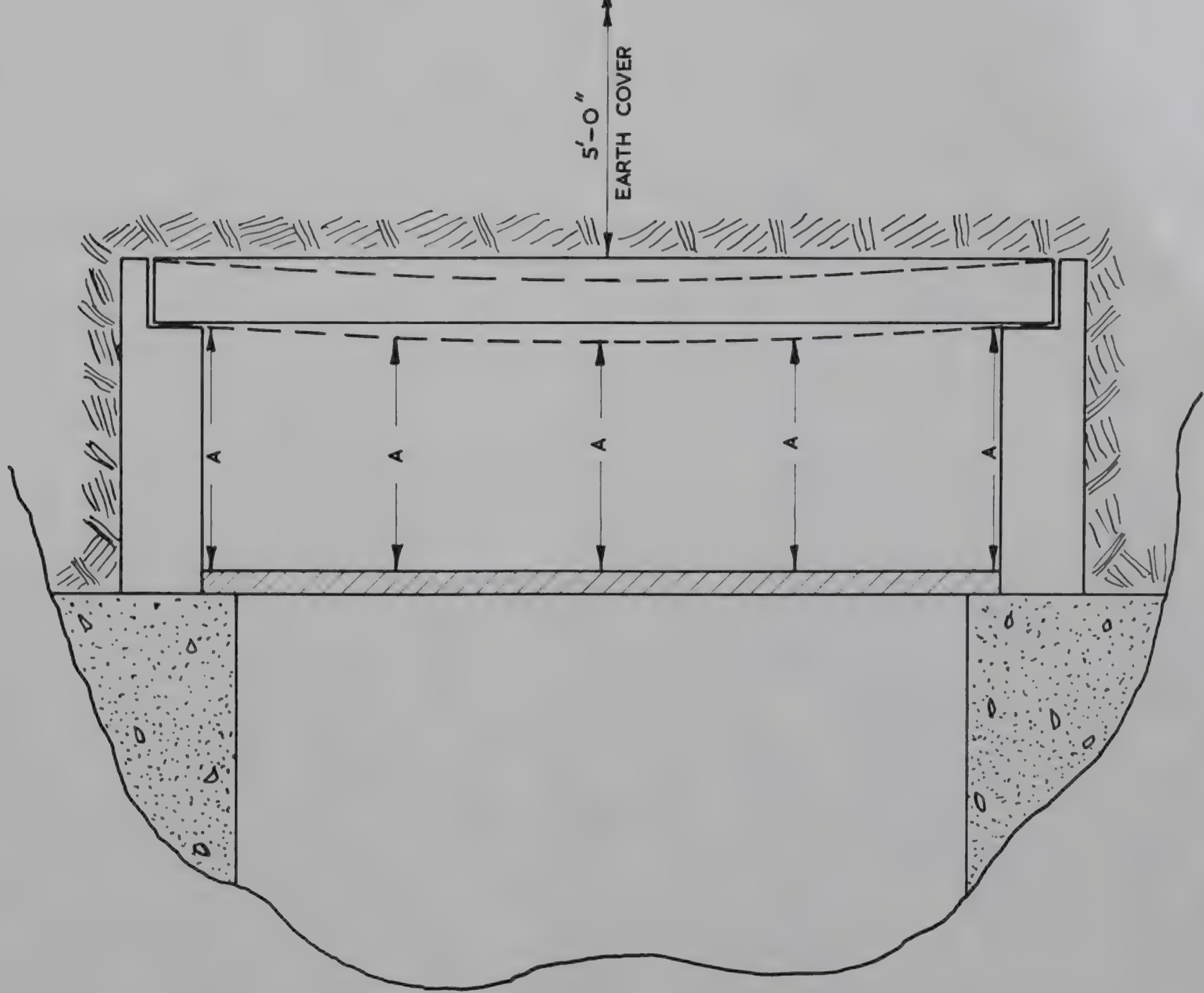


FIG.10. SKETCH SHOWING METHOD OF MEASURING DEFLECTION OF PANEL WITH 5FT EARTH COVER. MEASUREMENTS WERE TAKEN AT POINTS 'A'.

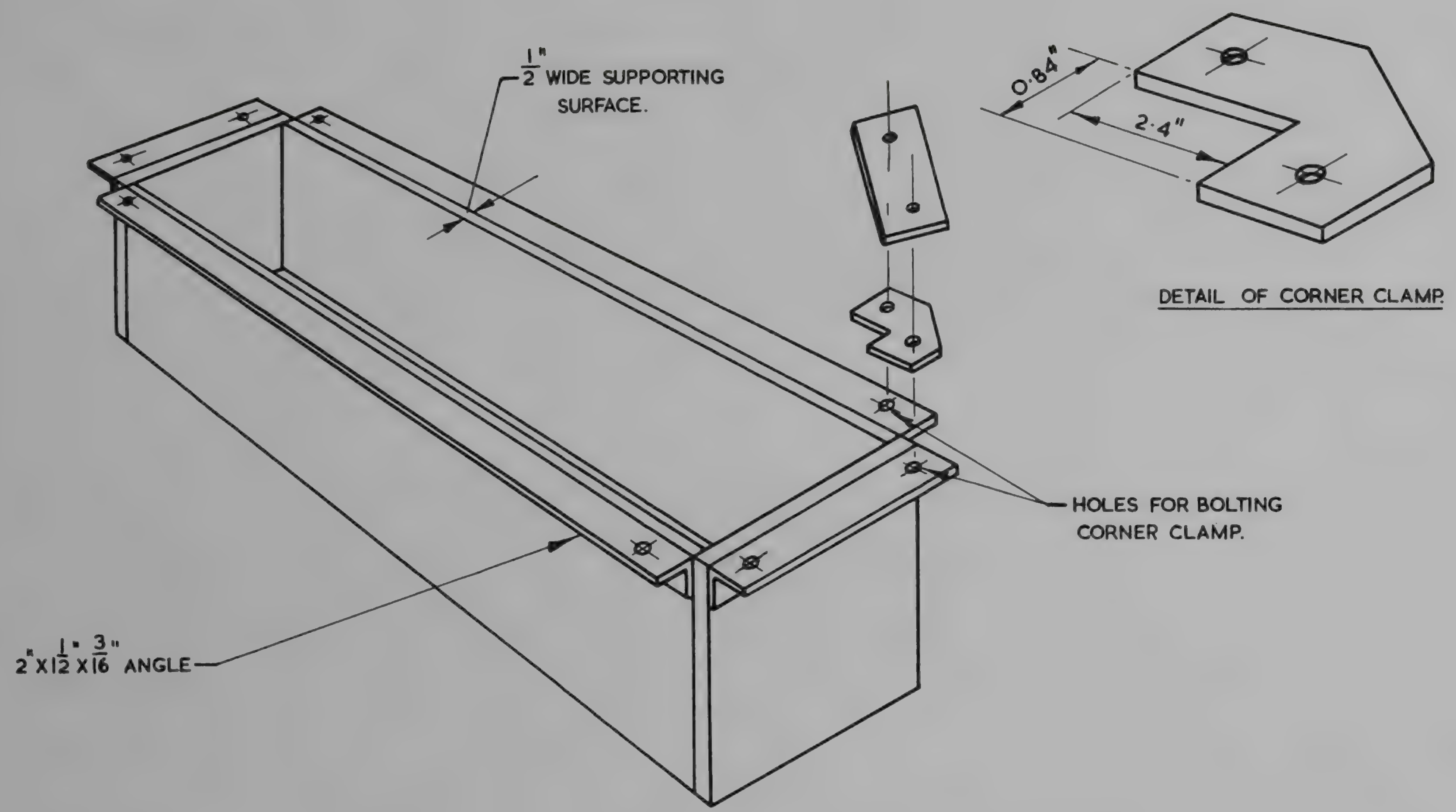


FIG. 11 STEEL BOX SUPPORT FOR MODEL PANEL.

FIG 12 MODEL PANEL IN SURFACE BEFORE FIRING.

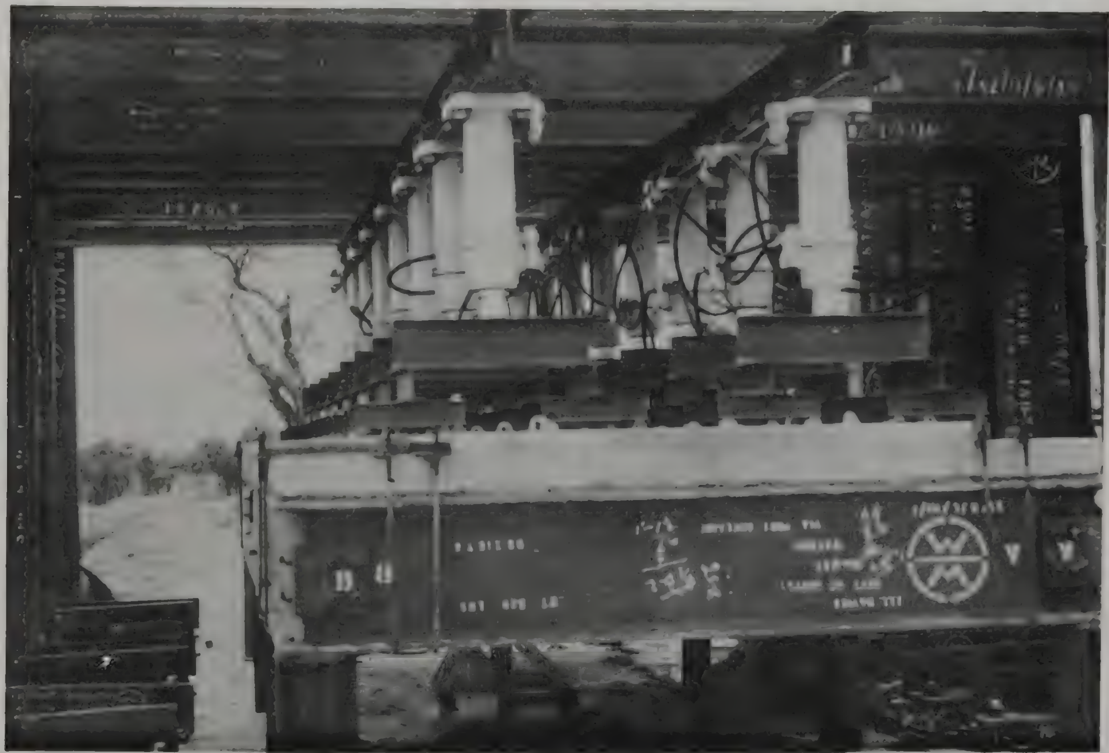


FIG 13 FULL SIZE PANEL SET UP IN TEST RIG READY FOR TEST.

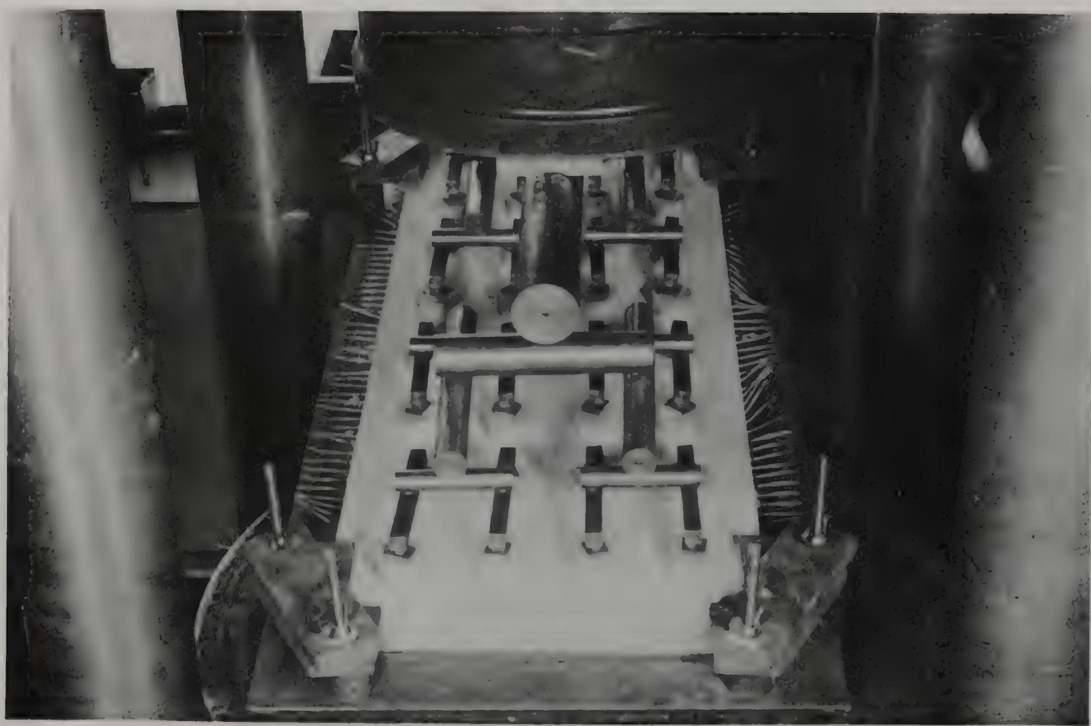


FIG. 14 PANEL READY FOR TESTING.

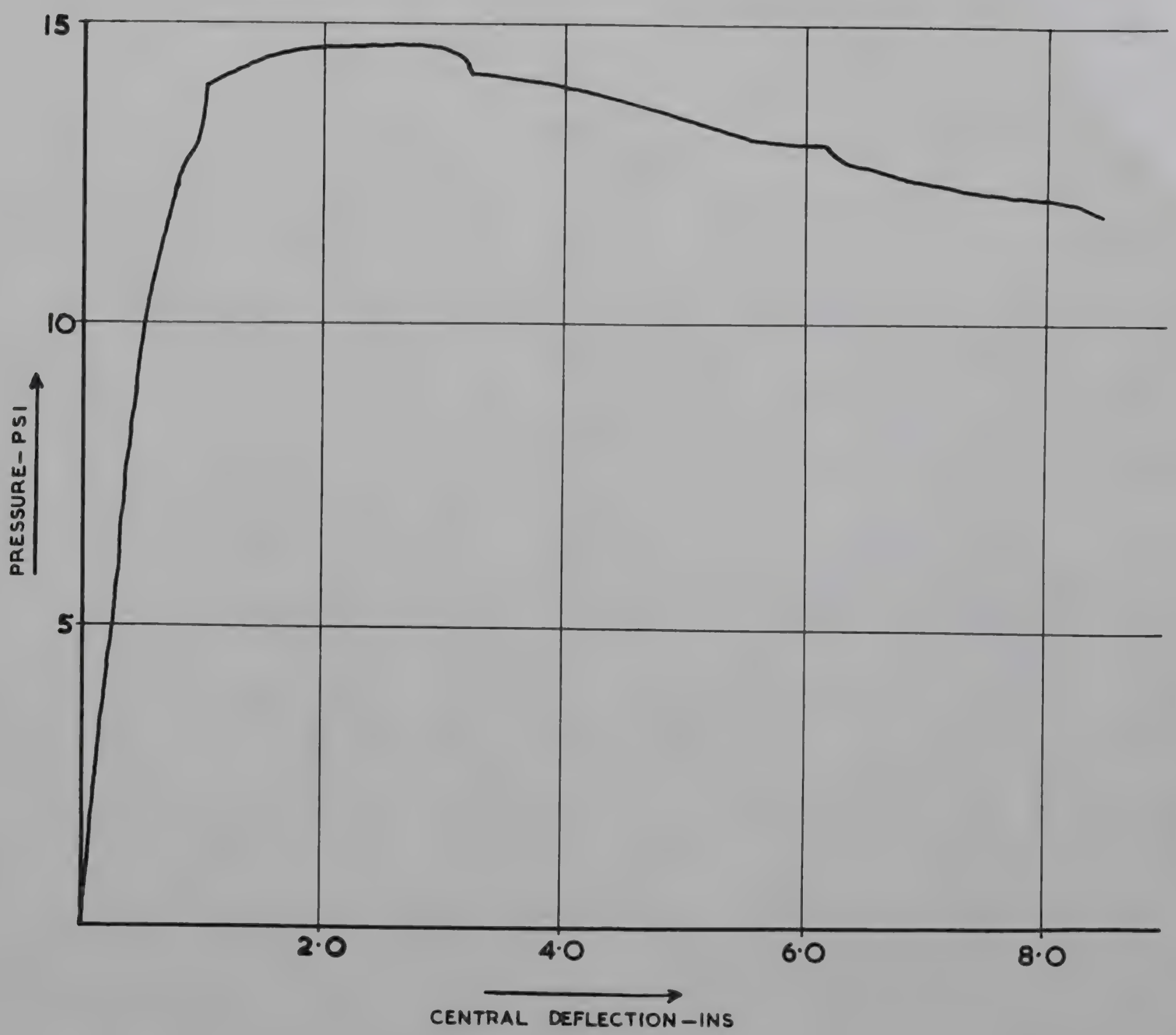


FIG 15 LOAD-DEFLECTION CURVE FOR FULL SCALE PANEL

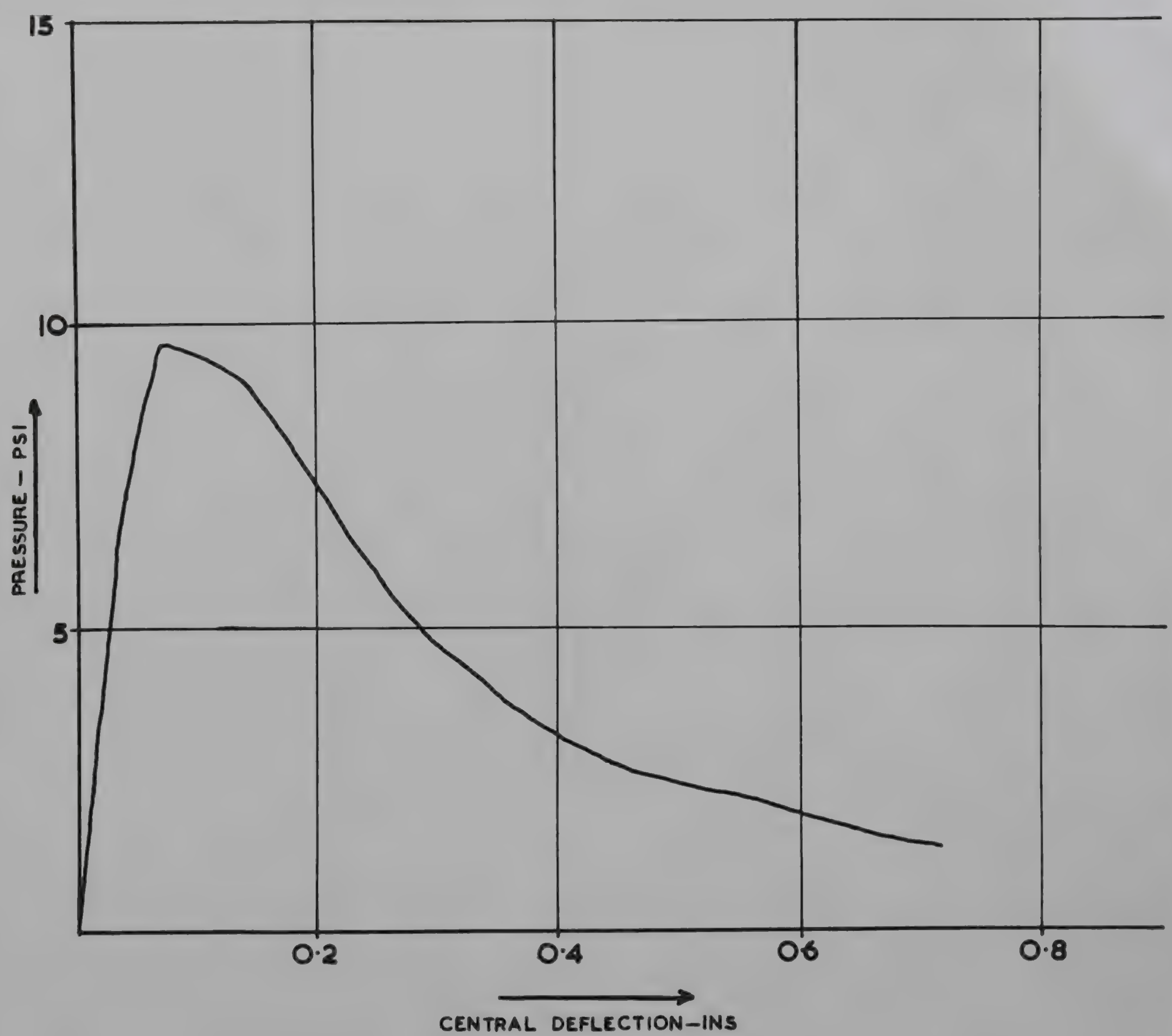


FIG 16 MEAN LOAD DEFLECTION CURVE FOR MODEL PANELS

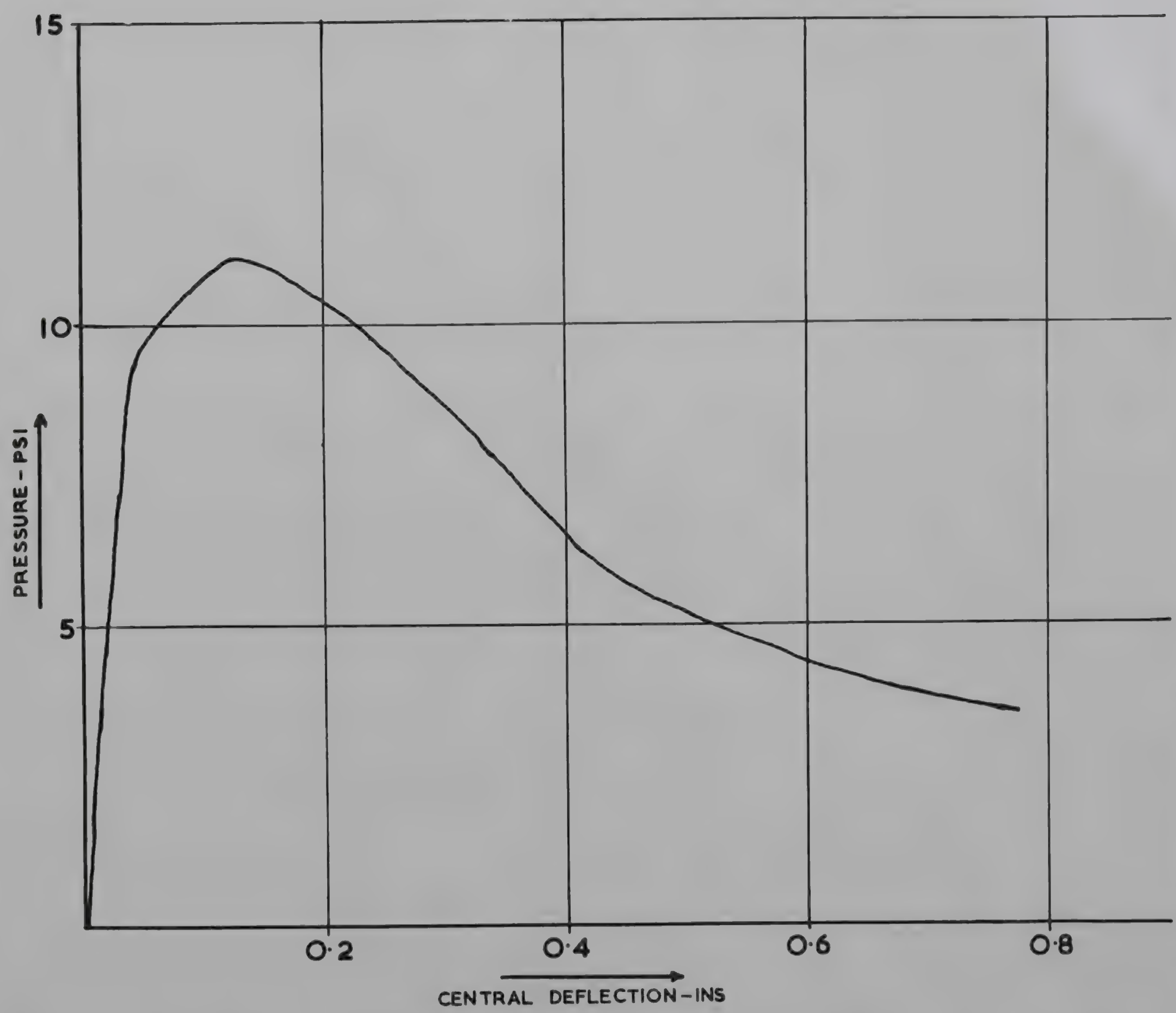
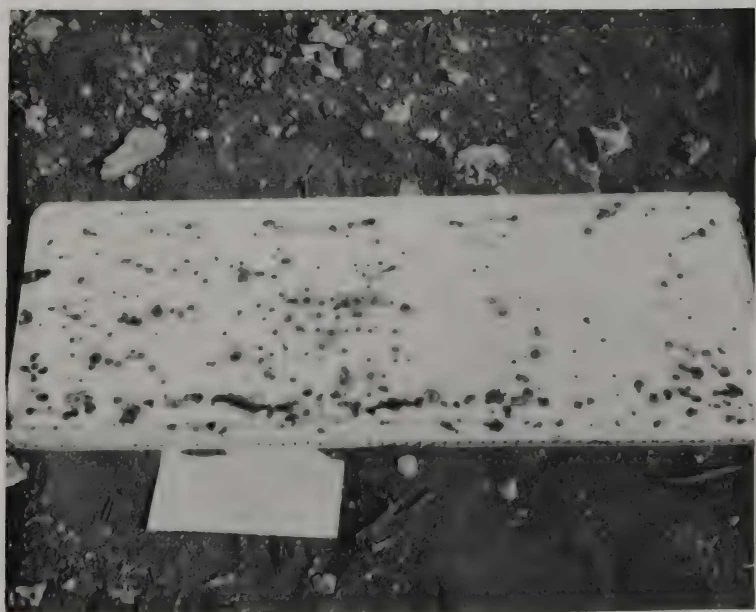


FIG 17. MEAN LOAD-DEFLECTION CURVE FOR MODEL PANELS CRACKED BEFORE TESTING

FIG. 18. DAMAGE TO FULL SCALE PANEL
AT 21·6 P.S.I.

TOP

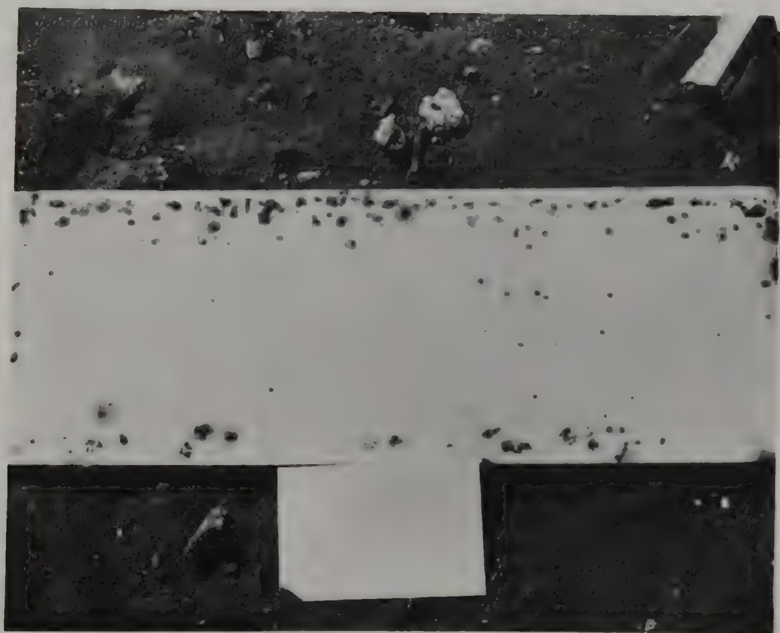


UNDERSIDE

FIG 19. DAMAGE TO MODEL PANEL WITH 6INS COVER

PRESSURE 17·9PSI RESIDUAL DEFLECTION 0·184INS

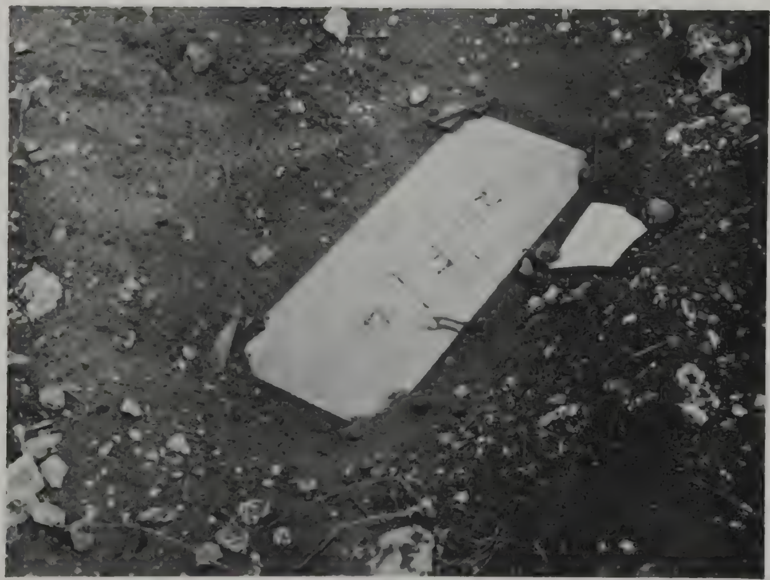
TOP



UNDERSIDE

FIG 20. DAMAGE TO MODEL PANEL WITH 6 INS COVER

PRESSURE 17·9 PSI RESIDUAL DEFLECTION 0·127 INS



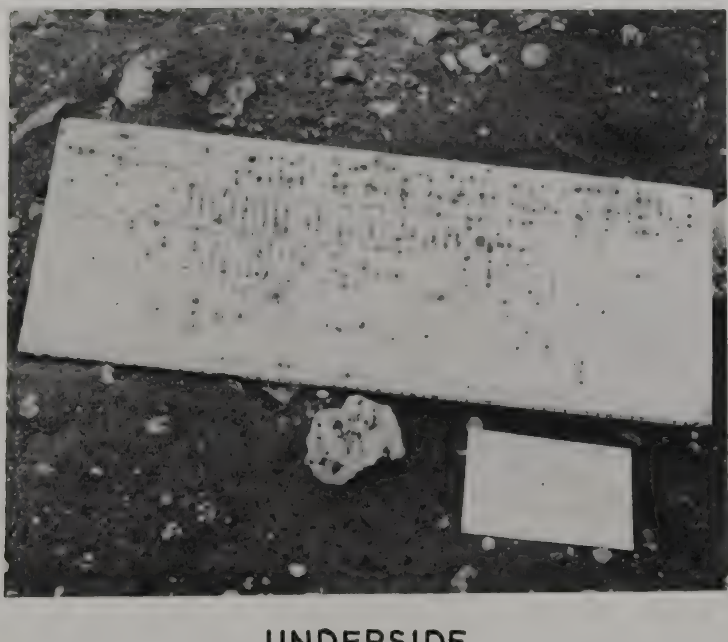
TOP

UNDERSIDE

FIG 21 DAMAGE TO MODEL PANEL WITH 6INS COVER

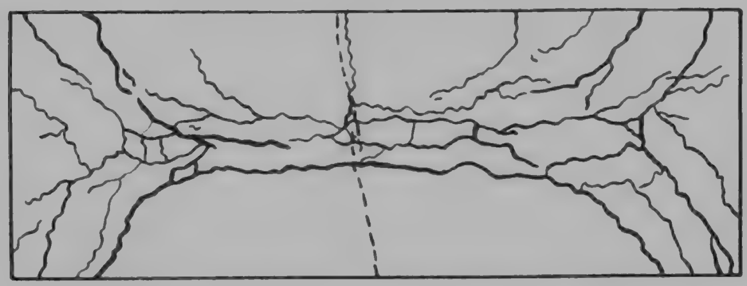
PRESSURE 13·2PSI RESIDUAL DEFLECTION 0·053INS

TOP



UNDERSIDE

FIG. 22. DAMAGE TO MODEL PANEL WITH 12 INS. COVER PRESSURE 12·0 PSI. RESIDUAL DEFLECTION 0·068 INS

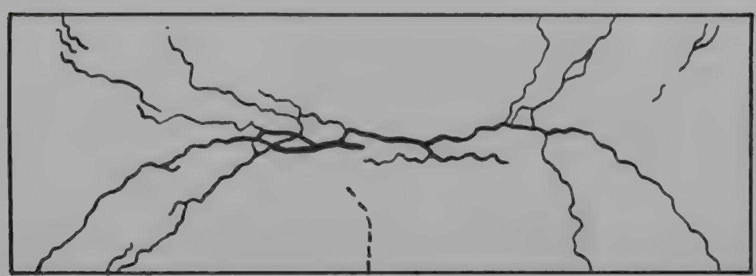


PANEL No 2a/A/2.

PRESSURE 27·0 P.S.I. RESIDUAL DEFLECTION 4·1 INS

PANEL No 2a/A/5

PRESSURE 17·9 P.S.I. RESIDUAL DEFLECTION 2·1 INS

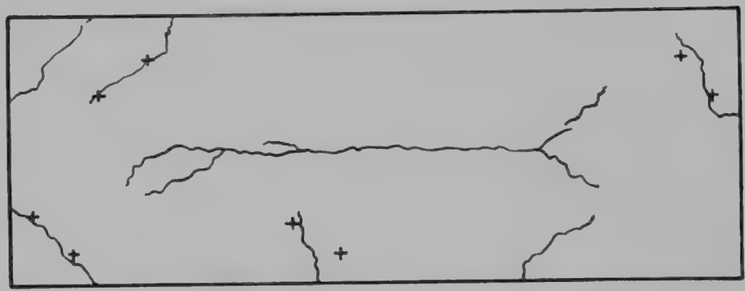


PANEL No 2a/A/7

PRESSURE 12·0 P.S.I. RESIDUAL DEFLECTION 0·8 INS

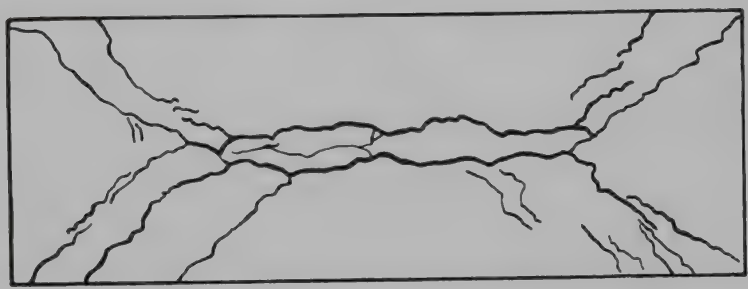
FIG 23 CRACK PATTERNS ON UNDERSIDE OF FULL SCALE PANELS WITH 5 FT EARTH COVER AFTER FIRING.

BROKEN LINE SHOWS INITIAL CRACKING ON TOP SURFACES.



LIFTING EYES SHOWN +

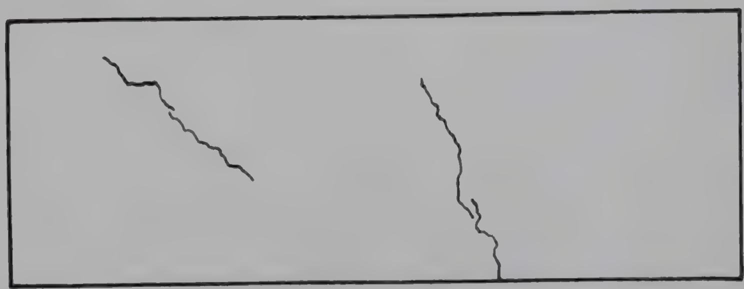
TOP.



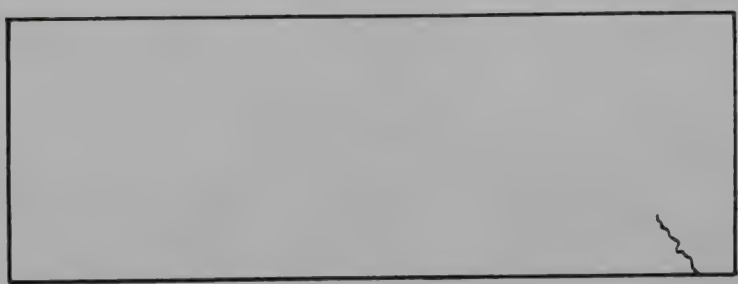
UNDERSIDE.

PANEL No 2a/A/6

PRESSURE 14·5 P.S.I. RESIDUAL DEFLECTION 0·9 INS.



TOP.



UNDERSIDE

PANEL No 2a/A/8

PRESSURE 10·3 P.S.I. RESIDUAL DEFLECTION 0·2 INS

FIG 24. CRACK PATTERNS ON FULL SCALE PANELS IN SURFACE AFTER FIRING.

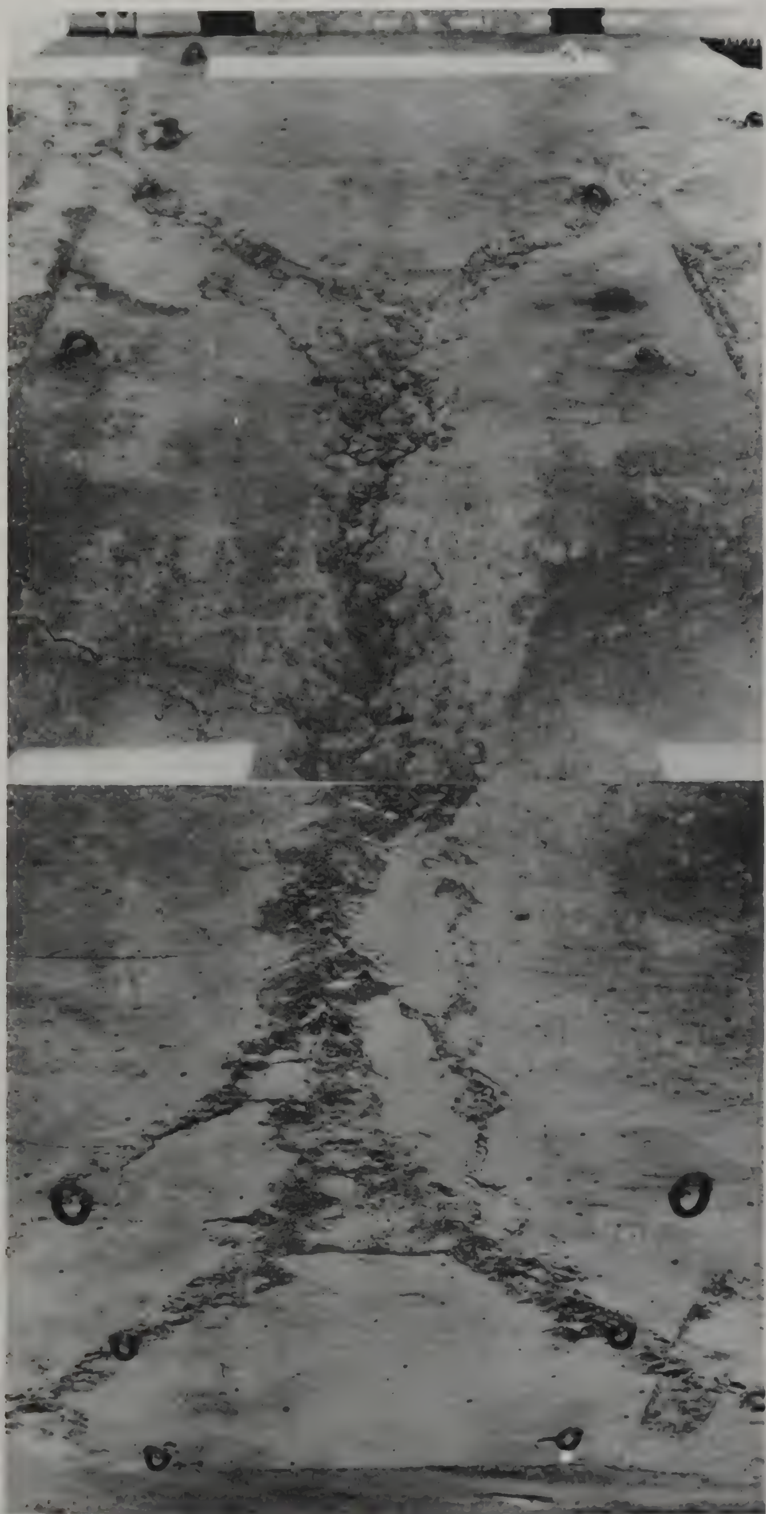
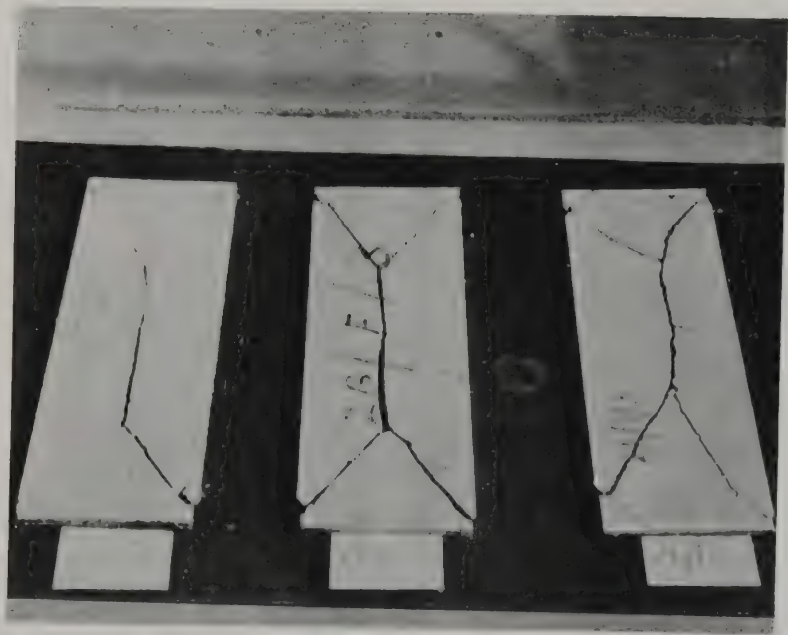


FIG 25. COMPOSITE PHOTOGRAPH OF TOP OF STATICALLY TESTED FULL SIZE PANEL



TOP

UNDERSIDE

FIG 26. TYPICAL DAMAGE TO MODEL PANELS UNDER STATIC LOADING

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ПОРАЖАЮЩИЕ ФАКТОРЫ ЯДЕРНОГО ВЗРЫВА
Damaging factors of a nuclear explosion
УДАРНАЯ ВОЛНА,
СРЕДСТВА ЗАЩИТЫ ОТ НЕЕ
BLAST WAVE
Means to protect against it
ОТКРЫТАЯ
ЩЕЛЬ
ПЕРЕКРЫТАЯ
ЩЕЛЬ
УБЕЖИЩЕ
Survival from GZ to R/10 radius
Underground concrete shelter
Survival at R/2 radius
Covered, shored trench
Survival at R radius
Open trench
СВЕТОВОЕ ИЗЛУЧЕНИЕ,
СРЕДСТВА ЗАЩИТЫ ОТ НЕГО
1976 and 1981 Russian nuclear shelters poster
50000 copies printed
People ducking and
covering behind
low walls, tree stumps
ПРОСТЕЙШЕЕ УКРЫТИЕ
(перекрытая щель)
УБЕЖИЩЕ
Shelter

ПОРАЖАЮЩИЕ ФАКТОРЫ ЯДЕРНОГО ВЗРЫВА

Damaging effects of a nuclear explosion

Ослабление интенсивности гамма-излучения характеризуется слоем половинного ослабления. Это слой вещества, при прохождении которого интенсивность гамма-лучей уменьшается в два раза.

Penetrating radiation - neutrons and gamma rays, are emitted during a nuclear explosion

Проникающая радиация — это поток гамма-лучей и нейтронов, испускаемых в момент ядерного взрыва.

Поражающее действие проникающей радиации на людей вызывается облучением, которое оказывает вредное биологическое действие на клетки организма, в результате чего человек заболевает так называемой лучевой болезнью.

В зависимости от дозы облучения (которая измеряется в рентгенах) различают три степени лучевой болезни: первую (легкую), вторую (среднюю) и третью (тяжелую).

При лучевой болезни первой степени скрытый период продолжается две-три недели, после чего появляется недомогание, общая слабость, тошнота, головокружение, повышается температура.

При лучевой болезни второй степени скрытый период длится около недели, признаки заболевания — как и при лучевой болезни первой степени, но в более ярко выраженной форме. При активном лечении выздоровление наступает через 1,5—2 месяца.

Скрытый период при лучевой болезни третьей степени сокращается до нескольких часов. Болезнь протекает более интенсивно. При активном лечении выздоровление наступает через несколько месяцев.

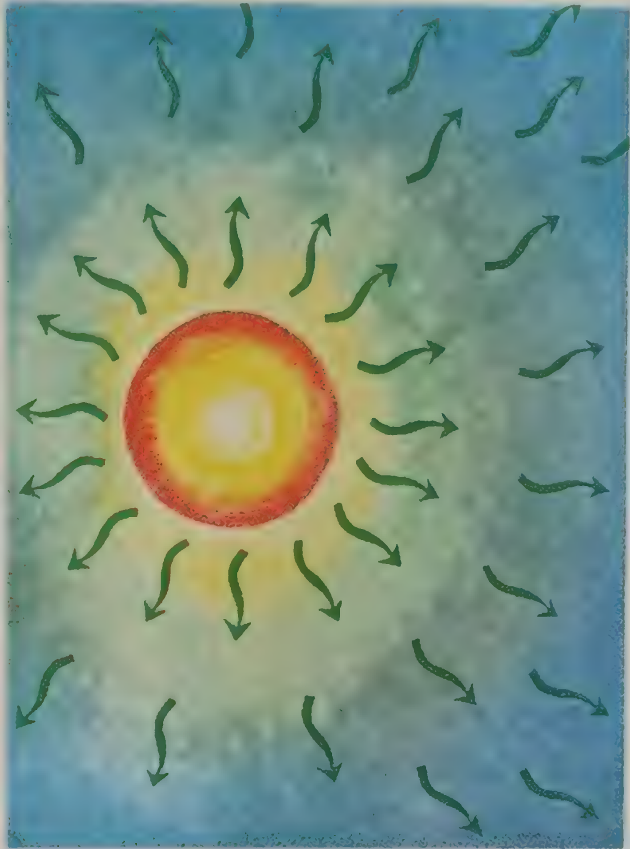
The first symptom of a mild (1st degree) radiation dose is brief nausea and sickness, followed by a latent period of no symptoms lasting 2-3 weeks, then another period of malaise/discomfort including symptoms of fever [due to low blood counts of radiation-susceptible short-lived white blood cells of the immune system, blood clotting platelets, etc.]. For moderately severe (2nd degree) doses, the latent period of no effects is reduced to just 1 week, and recovery with treatment takes 1.5-2 months. For severe (3rd degree) radiation doses, the latent period is reduced to a few hours.

ЕСЛИ ДОЗЫ ОБЛУЧЕНИЯ ПРЕВЫШАЮТ ДОПУСТИМЫЕ, ЧЕЛОВЕК ЗАБОЛЕВАЕТ ЛУЧЕВОЙ БОЛЕЗНЬЮ!

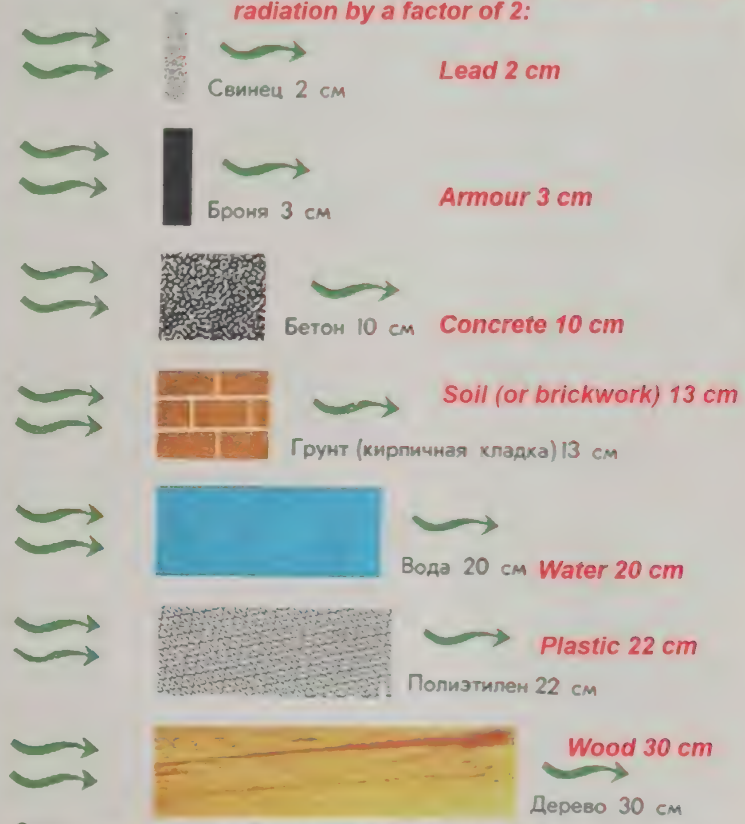
If the radiation dose exceeds permissible limits, the person becomes ill with radiation sickness

СТЕПЕНИ ЛУЧЕВОЙ БОЛЕЗНИ

100-200 р — лучевая болезнь I степени
100-200 R - mild 1st degree sickness
200-300 р — лучевая болезнь 2 степени
200-300 R - moderate or 2nd degree
300-450 р — лучевая болезнь 3 степени
300-450 R - severe or 3rd degree



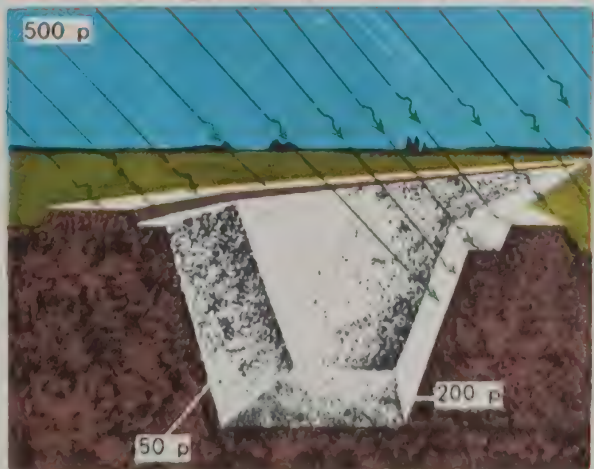
Thicknesses of material to reduce gamma radiation by a factor of 2:



Слой половинного ослабления некоторых материалов

За преградами доза радиации значительно меньше, чем на открытой местности. Убежища практически полностью защищают от радиации.

Behind barriers, radiation doses are much less. Shelters provide almost complete protection against radiation.



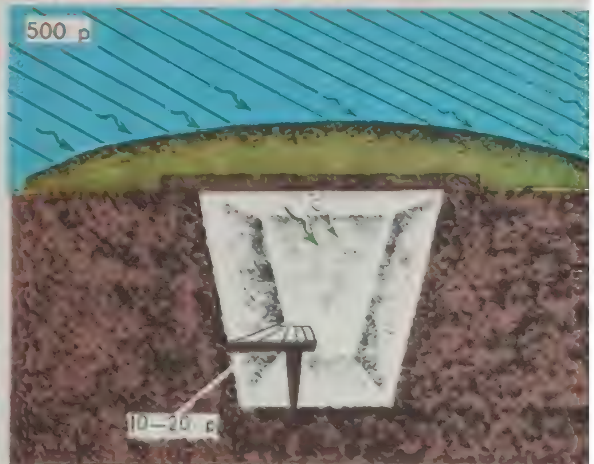
500 R reduced to 50-200R in open trench

Открытые щели ослабляют радиацию в 3—10 раз

Open slit trenches give a 3-10 fold shielding of gamma radiation

Перекрытые щели ослабляют радиацию в 25—50 раз

Covered trench gives 25-50 fold reduction (i.e. 500 R to 10-20 R)



УБЕЖИЩА, ПОСТРОЕННЫЕ С УЧЕТОМ ИХ ИСПОЛЬЗОВАНИЯ В МИРНОЕ ВРЕМЯ ДЛЯ НУЖД НАРОДНОГО ХОЗЯЙСТВА

SHELTERS BUILT TAKING INTO ACCOUNT THEIR USE IN PEACETIME FOR THE NEEDS OF THE NATIONAL ECONOMY

К убежищам предъявляются специальные требования: надежность защитных устройств и внутреннего оборудования; возможность самостоятельного выхода людей после ядерного взрыва, использование в мирное время для нужд народного хозяйства.

Подземные гаражи, предприятия общественного питания, склады, шахты и горные выработки обладают большой прочностью и имеют необходимое оборудование. В военное время они могут быть быстро подготовлены для укрытия людей.

Shelters must have reliable protection and equipment and an escape exit for emergencies where the entrance is blocked, and peacetime uses for economy. Underground garages, catering establishments, warehouses, mines and mine workings are highly durable and have the necessary equipment. In wartime, they can be quickly prepared to shelter people.

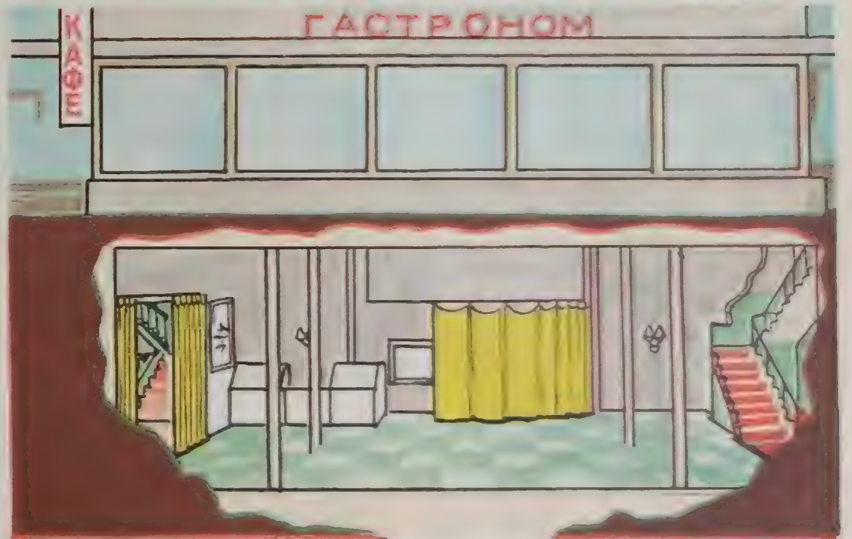
Метрополитены обладают высокими защитными свойствами и являются наиболее современным коллективным средством защиты людей от оружия массового поражения

Metro railway station dual use as deep nuclear war shelter (subway/underground/tube)

КОЭФФИЦИЕНТ ОСЛАБЛЕНИЯ ИЗЛУЧЕНИЯ:

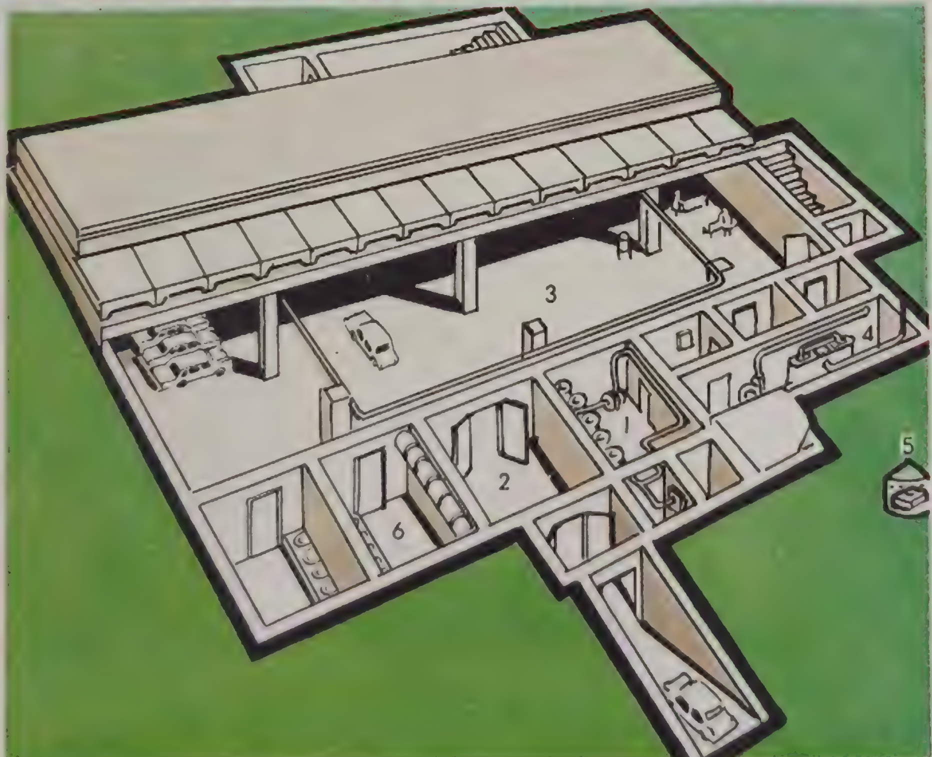
Каменное одноэтажное строение	10—13	раз
Подвал каменного одноэтажного строения	40—60	»
Каменное двухэтажное строение	15—20	»
Подвал каменного двухэтажного строения	100—130	»
Каменное трехэтажное строение	20—33	раза
Подвал каменного трехэтажного строения	400—600	раз
Перекрытые щели	40—50	»
Противорадиационные укрытия и убежища	400—1000	»
Пассажирские вагоны	3	раза
Грузовые вагоны	2	»
Кабины бульдозеров, кранов	4	»
Шахты, горные выработки — облучение практически исключено		

Radiation protection factors: 1-story house 10-13; basement of 1-story house 40-60; 2-story house 15-20; basement of 2-story house 100-130; ... shelters 400-1000



Убежище, построенное с учетом использования его в мирное время под кафетерии

Dual use underground basement shelter built for use as a cafeteria in in peacetime



Dual use underground large capacity car park/garage, with equipment to allow immediate conversion into a shelter

Отдельно стоящее убежище — гараж большой вместимости:

1 — помещение фильтровентиляционного оборудования; 2 — тамбур-шлюз с защитно-герметическими дверями (воротами); 3 — помещение для укрываемых; 4 — помещение для электрогенераторов с дизельными установками; 5 — вентиляционный оголовок с защитным устройством для отсекания ударной волны; 6 — помещение санузла с резервуаром запаса воды *water tank*

Специально оборудованная шахта

Mine equipped for dual use as a shelter


ПРОТИВОРАДИАЦИОННЫЕ УКРЫТИЯ (ПРУ)
Anti-radiation shelters
ПОДВАЛЬНОЕ ПОМЕЩЕНИЕ ШКОЛЫ,
ПРИСПОСОБЛЕННОЕ
ПОД ПРУ
School basement adapted into fallout shelter
Basement
shelter
(adapted)
ПОДВАЛ,
ПРИСПОСОБЛЕННЫЙ
ПОД ПРУ
1976-81
poster;
50,000
copies
printed
Cellar adapted into a
nuclear bomb shelter
ПОГРЕБ,
ПРИСПОСОБЛЕННЫЙ
ПОД ПРУ


ФИЛЬТРУЮЩИЕ ПРОТИВОГАЗЫ
ОБЕСПЕЧИВАЮТ ЗАЩИТУ ОТ ПОПАДАНИЯ В ОРГАНЫ ДЫХАНИЯ, ГЛАЗА И НА ЛИЦО РАДИОАКТИВНЫХ, ОТРАВЛЯЮЩИХ ВЕЩЕСТВ И БАКТЕРИАЛЬНЫХ (БИОЛОГИЧЕСКИХ) СРЕДСТВ
ПРОТИВОГАЗЫ ДЛЯ ВЗРОСЛЫХ
ОБЩЕВОЙСКОВОЙ ПРОТИВОГАЗ
ГП-5
ГП-4у
ДЕТСКИЕ ПРОТИВОГАЗЫ
ПДФ-Ш
ПДФ-7
ДП-6
50000 copies
1986 Russian gas masks poster

В местах с неустойчивыми грунтами укрытия строятся с одеждой крутостей (откосы котлованов укрепляются блоками). Десять человек могут построить для себя такое укрытие за 19 часов. Для этого необходимо иметь 1500 шт. блоков, 9 м³ глиняного раствора и несколько досок для устройства входа и вентиляционного короба.

Translation: this shelter for places with unstable soil was made by the occupants in 19 hours, using 9 cubic metres of clay in 1500 blocks.

Extract from 1972 Russian nuclear shelters poster "Anti-radiation shelters made of Adobe blocks" giving several designs that have a fallout gamma radiation protection factor of 400-700, using adobe/clay blocks.

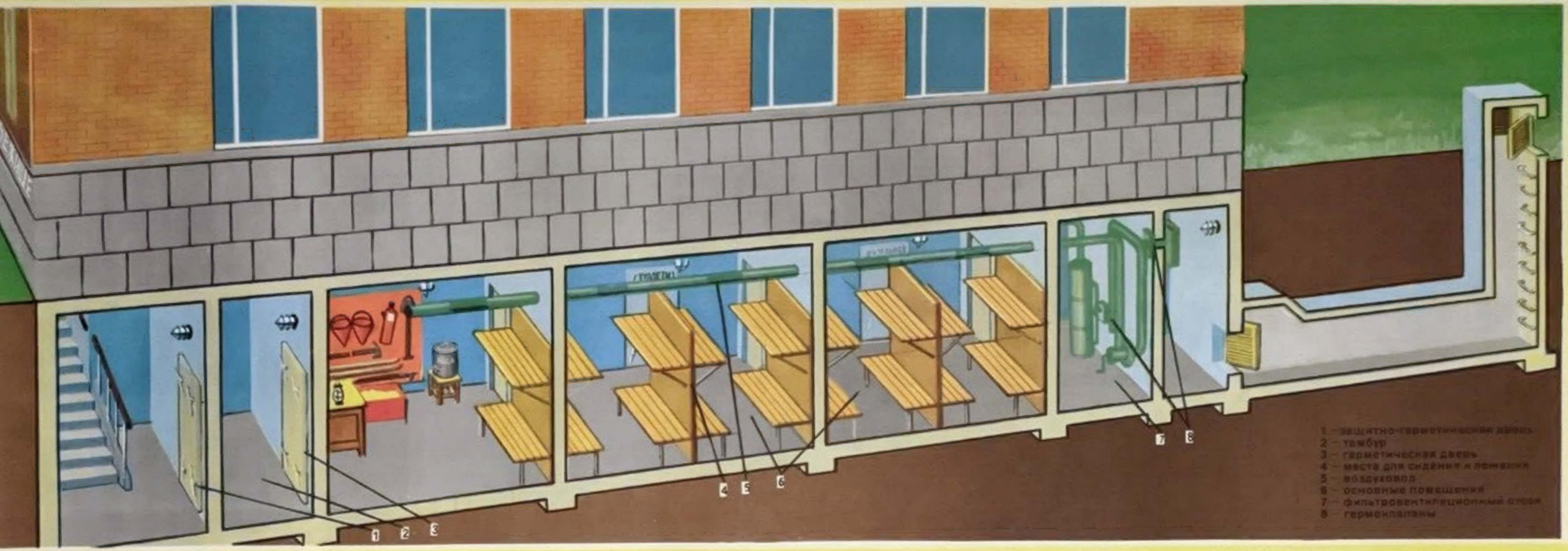

ЗАЩИТНЫЕ СООРУЖЕНИЯ ГО
1986-7 Russian double blast door concrete basement shelter; 50,000 copies of poster
Противорадиационное укрытие — сооружение, обеспечивающее защиту людей от ионизирующих излучений при радиоактивном заражении местности и светового потока, частично от ударной волны и проникающей радиации (в том числе и от нейтронного потока), а также от непосредственного попадания на кожу и одежду людей радиоактивных, отравляющих веществ и бактериальных средств
Concrete slabs covered shelter
ПРОТИВОРАДИАЦИОННОЕ УКРЫТИЕ ИЗ ЛЕСОМАТЕРИАЛА С ПЕРЕКРЫТИЕМ ИЗ ЖЕЛЕЗОБЕТОННЫХ ПЛИТ
ПОГРЕБ, ПРИСПОСОБЛЕННЫЙ ПОД УКРЫТИЕ
Farm cellar shelter
Оконные ставни
Насыпь грунта на перекрытии
Дополнительная кирпичная кладка
Приточный короб
Стойка усиления
Оконные проемы заложенные кирпичом
Грунтовая обсыпка
Basement shelter
Вытяжной короб
ПОДВАЛЬНОЕ ПОМЕЩЕНИЕ, ПРИСПОСОБЛЕННОЕ ПОД ПРУ
УСТРОЙСТВО И ВНУТРЕННЕЕ ОБОРУДОВАНИЕ УБЕЖИЩА
Убежище — сооружение герметического типа, предназначенное для защиты укрывающихся в нем людей от всех поражающих факторов ядерного взрыва, отравляющих веществ, бактериальных средств, а также от высоких температур и вредных газов, образующихся при пожарах
(1) & (3): DOUBLE BLAST DOORS FOR HIGH LEVEL OF BLAST PROTECTION
DOUBLE BLAST DOORS CONCRETE BASEMENT SHELTER

ОБЩЕЕ УСТРОЙСТВО УБЕЖИЩ

1980 Russian nuclear shelters poster

УБЕЖИЩА ЗАЩИЩАЮТ ЛЮДЕЙ ОТ ВОЗДЕЙСТВИЯ ЯДЕРНОГО ОРУЖИЯ, ОТРАВЛЯЮЩИХ ВЕЩЕСТВ И БАКТЕРИАЛЬНЫХ СРЕДСТВ

ВНУТРЕННЕЕ ОБОРУДОВАНИЕ ВСТРОЕННОГО УБЕЖИЩА



DOUBLE BLAST DOORS FOR CLOSE-IN HIGH OVERPRESSURES

По сигналу «Воздушная тревога» в убежище (укрытие) сначала размещаются дети и престарелые люди;

индивидуальные средства защиты необходимо держать в постоянной готовности;

общий выход из убежища осуществляется по сигналу «Отбой воздушной тревоги» (без разрешения выходить из убежища запрещается).

Основные помещения строятся из расчета 1,5 м^3 объема и 0,5 м^2 площади на одного укрываемого человека.

Высота помещений должна составлять не менее 2,2 м от пола до низа выступающих конструкций перекрытия.

Места для сидения устраиваются размером 0,45x0,45 м на одного человека и для лежания на верхнем ярусе 0,55x1,8 м. Количество мест для лежания должно быть не менее 20% от общей вместимости убежища.

В убежище в противоположных его концах устраивается не менее двух выходов.

Очистка подаваемого воздуха может осуществляться в двух режимах: чистой вентиляции (очистка воздуха от пыли), фильтровентиляции (очистка воздуха от пыли и ОВ).

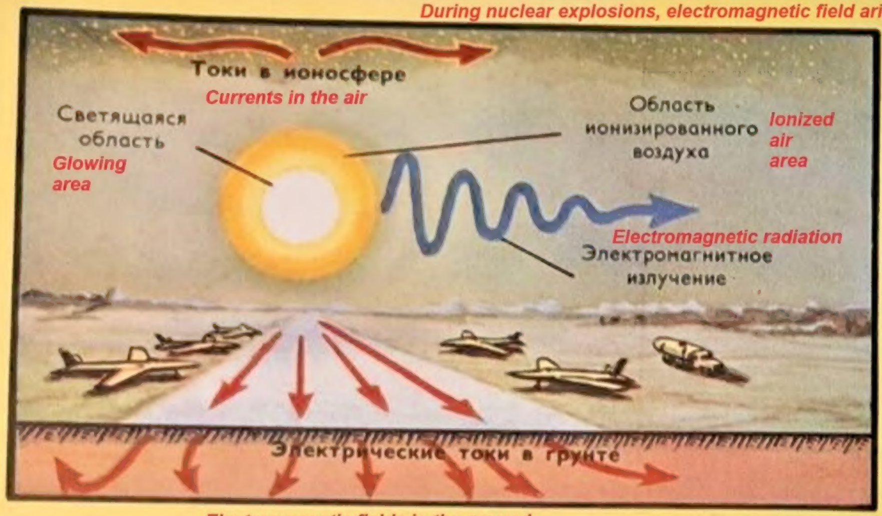
РАЗМЕЩЕНИЕ ЛЮДЕЙ В УБЕЖИЩЕ

Таблицы по гражданской обороне. 5класс
УБЕЖИЩЕ И ПРОСТЕЙШИЕ УКРЫТИЯ
Shelters and the simplest protective structures
1976-1981 Russian shelter poster, 50,000 copies printed
ТАМБУР
ВОЗДУХОВОД
ОСНОВНЫЕ ПОМЕЩЕНИЯ
ОГОЛОВОК
ЗАПАСНОЙ ВЫХОД
ФИЛЬТРОВЕНТИЛЯЦИОННЫЙ ОТСЕК
Double doors
Hemetic door
ГЕРМЕТИЧЕСКАЯ ДВЕРЬ
ЗАЩИТНО-ГЕРМЕТИЧЕСКАЯ ДВЕРЬ
Protective hermetic blast door
НАРЫ
Bunks
УСТРОЙСТВО И ВНУТРЕННЕЕ ОБОРУДОВАНИЕ ВСТРОЕННОГО УБЕЖИЩА
The device and built-in equipment of the built-in (basement) shelter
NOTETHE DOUBLE BLAST DOORS FOR CLOSE-IN BLAST PROTECTION
Bunks at top (take turns to sleep)
Blast door
РАЗМЕЩЕНИЕ ЛЮДЕЙ В УБЕЖИЩЕ
People in shelter
ОТКРЫТАЯ ЩЕЛЬ
Simplest shelters (open trench)
ПЕРЕКРЫТАЯ ЩЕЛЬ
ПРОСТЕЙШИЕ УКРЫТИЯ
(covered trench)

ЭЛЕКТРОМАГНИТНЫЙ ИМПУЛЬС *Electromagnetic pulse*

ПРИ ЯДЕРНЫХ ВЗРЫВАХ ВОЗНИКАЮТ ЭЛЕКТРОМАГНИТНЫЕ ПОЛЯ, КОТОРЫЕ СОЗДАЮТ ИМПУЛЬСНЫЕ ЭЛЕКТРИЧЕСКИЕ ТОКИ И НАПРЯЖЕНИЯ В ВОЗДУШНЫХ И НАЗЕМНЫХ ПРОВОДНЫХ И КАБЕЛЬНЫХ ЛИНИЯХ, В АНТЕННАХ РАДИОСТАНЦИЙ, А ТАКЖЕ РАДИОИЗЛУЧЕНИЕ, РАСПРОСТРАНЯЮЩЕЕСЯ НА БОЛЬШИЕ РАССТОЯНИЯ.

During nuclear explosions, electromagnetic field arise, which create pulsed electric currents and voltages on ground-based wire an cable lines, radio antennas, and radiated radio energy spreading far

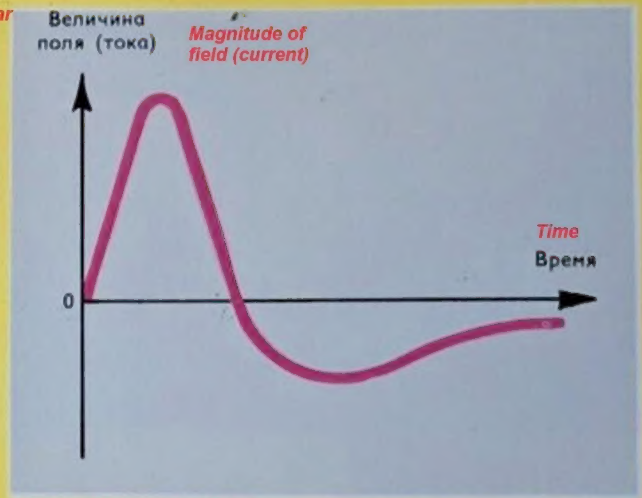


Электромагнитное поле и токи в воздухе и грунте возникают в результате образования в зоне взрыва светящейся области и большой области ионизированного воздуха, созданной проникающей радиацией.

Electromagnetic fields and currents in the air and the ground, arise in the ionized air created by the penetrating radiation from the explosion.

Наведенные токи и напряжения представляют собой кратковременный импульс, по своим характеристикам близкий к импульсу, вызванному молниевым разрядом. Его длительность составляет несколько миллисекунд.

Induced voltages and currents are in the form of a pulse, similar to lightning, with a duration of several milliseconds.



Within several km of air and ground explosions, overhead power/communications lines experience 10,000 - 100,000 volt induced pulses

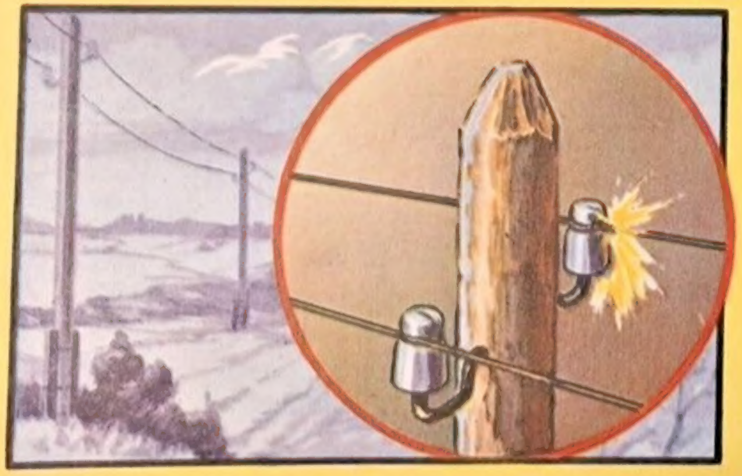
ПРИ НАЗЕМНЫХ И ВОЗДУШНЫХ ВЗРЫВАХ В РАДИУСЕ НЕСКОЛЬКИХ КИЛОМЕТРОВ ОТ ЦЕНТРА (ЭПИЦЕНТРА) ВЗРЫВА ПЕРЕНАПРЯЖЕНИЯ МЕЖДУ ПРОВОДАМИ ВОЗДУШНЫХ ЛИНИЙ СВЯЗИ ИЛИ ЭЛЕКТРОСНАБЖЕНИЯ И ЗЕМЛЕЙ ДОСТИГАЮТ ДЕСЯТКОВ И СОТЕН ТЫСЯЧ ВОЛЬТ, А МЕЖДУ ЖИЛАМИ ПОДЗЕМНЫХ КАБЕЛЬНЫХ ЛИНИЙ И ОБОЛОЧКОЙ (ЗЕМЛЕЙ) — НЕСКОЛЬКИХ ДЕСЯТКОВ ТЫСЯЧ ВОЛЬТ. НАВЕДЕННЫЕ ИМПУЛЬСЫ МОГУТ РАСПРОСТРАНЯТЬСЯ ПО ЛИНИЯМ НА БОЛЬШИЕ РАССТОЯНИЯ ОТ МЕСТА ЯДЕРНОГО ВЗРЫВА.

Underground cables receive several tens of thousands of volts induced pulse

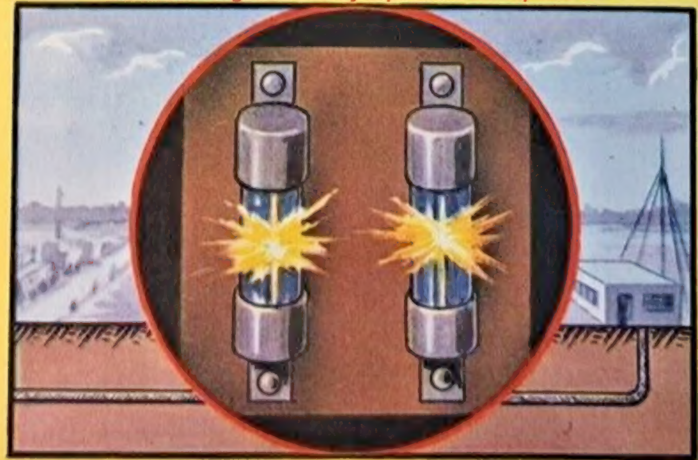
Induced pulse propagate out to long distances along the transmission lines

ВОЗНИКШИЕ ПРИ ВЗРЫВАХ ПЕРЕНАПРЯЖЕНИЯ СПОСОБНЫ:

The over-voltages caused by explosions are capable of



разрушать изоляцию электро- и радиотехнических устройств; *Destroying the insulation of electrical and radio equipment*



вызывать перегорание элементов электро- и радиоаппаратуры или массовое срабатывание средств защиты; *Burning out electrical and radio equipment components/safety devices.*

поражать обслуживающий персонал. *Injuring technical staff.*

РАССРЕДОТОЧЕНИЕ И ЭВАКУАЦИЯ
Dispersal and evacuation
РАССРЕДОТОЧЕНИЕ — ОРГАНИЗОВАННЫЙ ВЫВОЗ ИЗ КРУПНЫХ ГОРОДОВ И РАЗМЕЩЕНИЕ В ЗАГОРОДНОЙ ЗОНЕ РАБОЧИХ, СЛУЖАЩИХ ПРЕДПРИЯТИЙ И ОРГАНИЗАЦИЙ, ПРОДОЛЖАЮЩИХ ПРОИЗВОДСТВЕННУЮ ДЕЯТЕЛЬНОСТЬ В ГОРОДЕ
Dispersal is organized removal of personnel from cities to continue work small towns
ЭВАКУАЦИЯ — ОРГАНИЗОВАННЫЙ ВЫВОД (ВЫВОЗ) ИЗ КРУПНЫХ ГОРОДОВ РАБОЧИХ, СЛУЖАЩИХ ПРЕДПРИЯТИЙ, ОРГАНИЗАЦИЙ, ПЕРЕНОСЯЩИХ СВОЮ ДЕЯТЕЛЬНОСТЬ В ЗАГОРОДНУЮ ЗОНУ, А ТАКЖЕ НЕТРУДОСПОСОБНОГО И НЕ ЗАНЯТОГО В ПРОИЗВОДСТВЕ НАСЕЛЕНИЯ
Evacuation is the organized removal of people to rural areas
ПРИНЦИПИАЛЬНАЯ СХЕМА РАССРЕДОТОЧЕНИЯ И ЭВАКУАЦИИ НАСЕЛЕНИЯ
Schematic diagram of the dispersal and evacuation of the population
Районы размещения рассредотачиваемого населения
Районы размещения эвакуируемого населения
Конечные пункты
СБОРНЫЙ ЭВАКУАЦИОННЫЙ ПУНКТ
Сборные эвакуационные пункты предназначены для сбора, регистрации и отправки в загородную зону рассредотачиваемых рабочих и служащих и эвакуируемого населения
Станция пересадки
Конечный пункт
В сельской местности создаются эвакоприемные комиссии и приемные эвакопункты. Они предназначены для обеспечения встречи, учета и отправки прибывшего населения до конечных пунктов размещения
1986-1986 Russian poster, 50,000 copies printed
СССР
ПАСПОРТ
ДИПЛОМ
С получением распоряжения о начале рассредоточения и эвакуации надо: взять с собой личные документы, средства индивидуальной защиты, самые необходимые вещи и продукты питания на 2—3 дня; подготовить квартиру: снять занавески и шторы с окон, выключить электричество, газ и воду, сдать квартиру представителям ЖЭК
Немедленно отправиться на сборный эвакуационный пункт